UNCLASSIFIED

AD NUMBER
AD314661
CLASSIFICATION CHANGES
TO: **unclassified**
FROM: **confidential**
LIMITATION CHANGES
TO: **Approved for public release, distribution unlimited**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 07 DEC 1959. Other requests shall be referred to Bureau of Ordnance, Department of the Navy, Washington, DC 20350.**
AUTHORITY
USNSWC notice dtd 7 Nov 1978; USNSWC notice dtd 7 Nov 1978

THIS PAGE IS UNCLASSIFIED

AD 314661

DEFENSE DOCUMENTATION CENTER

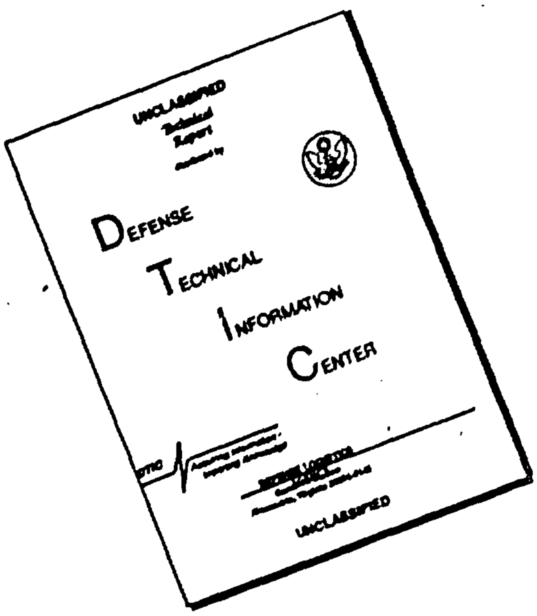
FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION ALEXANDRIA, VIRGINIA

UNCLASSIFIED

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

NWL Report No. 1683
Copy No. 14

(10)

THEORETICAL PREDICTIONS OF THE FIRST MAXIMUM PITCH OF LOW DRAG BOMBS RELEASED FROM A3D AIRCRAFT IN HORIZONTAL FLIGHT (U)

DEPARTMENT OF THE NAVY
BUREAU OF ORDNANCE

FC

U. S. NAVAL WEAPONS LABORATORY
DAHLGREN, VIRGINIA

Date: 7 DECEMBER 1959

CONFIDENTIAL

U. S. Naval Weapons Laboratory
Dahlgren, Virginia

Theoretical Predictions of the First Maximum Pitch of Low Drag Bombs Released From A3D Aircraft in Horizontal Flight (U)

by

J. D. Kunlo
Computation and Analysis Laboratory

NWL REPORT NO. 1683

Task Assignment
NO 103-666-64042/01-064

7 December 1959

R. H. Lyddane

APPROVED: R. H. LYDDANE
Technical Director

RELEASED: A. R. FAUST
Captain, USN
Commander, U. S. Naval Weapons Laboratory

V V Utgoff

V. V. UTGOFF
Captain, USN
Ordnance Officer
By direction

CONFIDENTIAL

CONTENTS

ABSTRACT

This report presents the results of a study to determine a method of predicting the first maximum pitch of low drag bombs ejected from A3D type aircraft by means of the Aero 7A Bomb Ejector Rack. The conclusions reached herein are: (1) the theoretical solution assuming free stream conditions and linear aerodynamic moments is a satisfactory method of predicting first maximum pitch for the conditions under which the test data were obtained, (2) the difference between the observed first maximum pitch of the Mk 81 bomb with nose plug and that of the Mk 81 bomb with nose fuze is due to the difference in the positions of center of gravity which results in the bombs being ejected with different angular rates, (3) there is no apparent correlation between the magnitude of the first maximum pitch and the location of the bomb rack in the bomb bay, and (4) there is no difference apparent between the magnitudes of the first maximum pitch of those bombs that had bad flight and those bombs that had good flight (when released at the same conditions). In addition, it is believed that the theoretical free stream solution developed herein will satisfactorily predict the first maximum pitch of other bombs ejected from the A3D aircraft by the Aero 7A bomb rack provided that (a) the ejection velocity of the bombs is at least 10 feet per second, and (b) the angular velocity of the bombs does not exceed 300 degrees per second, and (c) the ratio of weight to longitudinal cross section area of the bombs is no smaller than that of the subject bombs. A study is now in progress to predict the range effects due to the first maximum pitch reported herein; if this study is concluded satisfactorily, one will have reasonable confidence that the procedures are suitable for use under a variety of conditions, thus eliminating the necessity of extensive ballistic tests for the purpose of preparing bombing tables for the A3D airplane.

FOREWORD

This report contains the results of a study to determine a method of predicting the first maximum pitch of low drag bombs released from the bomb bay of A3D airplane in horizontal flight. The tests that provide the basic data in this report were conducted at the Naval Weapons Laboratory between August 1956 and July 1957 under the direction of J. E. Mitchell, Computation and Analysis Laboratory. These tests were performed and the study was conducted under Task Assignment NO 103-666/64042/01-064. The Naval Air Test Center, Patuxent, Maryland provided the services of the A3D aircraft used in the tests discussed in this report. This report has been reviewed by:

A. L. JONES, Head, Theory and Analysis Division
R. A. NIEMANN, Director, Computation and Analysis Laboratory

INTRODUCTION

Ballistic tables for the low drag bombs with nose fuze plugs (Electric fuzes) are based on ballistic data obtained from drops at conditions which, it was believed, would produce small initial pitch. Photographic records and dispersion data indicate that these bombs usually had stable flight (i.e., about 90 percent of the bombs were stable). Later, for the purpose of determining whether the ballistic tables for the low drag bombs are applicable to release conditions other than those of the original tests, additional ballistic data were obtained for the Mk 81, Mk 82 and Mk 83 bombs released from the AD type airplane in a dive (see reference 1) and the Mk 81 and Mk 82 bombs released from the A3D airplane in horizontal flight (see reference 2).

Tests of the Mk 81 and Mk 82 bombs, with nose fuze plugs or with AN/M-103A1 mechanical nose fuze, released from A3D aircraft in horizontal flight indicated that these bombs were unsuitable for service use under the release conditions of the test (approximately 8,000 to 10,000 feet true altitude, 200 to 500 knots true airspeed) due to the large percentage of unstable flights encountered. These unstable flights were attributed to a large pitching motion developed immediately after release, which in turn results from ejecting the Mk 81 and Mk 82 bombs from the Aero 7A bomb ejector rack (the ejector foot of this rack contacts these bombs at a point 3 to 5 inches aft of the center of gravity of the bombs). Some methods of reducing this pitching motion were suggested and results from certain pertinent tests are reported in reference 3.

The Mk 81 and Mk 82 bombs will not be dropped under the conditions of the above tests because of the large percentage of unstable flights which would result. (See reference 4 which restricts the use of bombs below the 500 pound category; the 500 pound bomb is considered unsatisfactory but is not restricted.) However, other low drag bombs and Army-Navy type bombs are expected to have appreciable pitch when released from the A3D airplane. A modification of the ejector cartridge used with the Mk 82 bomb, now under consideration, is expected to result in lower but perhaps still appreciable pitch. It is therefore desirable to consider the results of the tests further in order to determine the best method of preparing bombing tables for

bombs released from the A3D aircraft with large initial pitch. Extensive tests to determine applicable bombing table data over the operational limits of the airplane would be expensive and time consuming. An alternate procedure is suggested in this report; namely, that the first maximum pitch of bombs released from the A3D airplane be predicted by theoretical means by considering the pitching moment produced by the Aero 7A rack and assuming free stream conditions (i.e., assuming that the airflow on the bomb at the instant of release is equivalent to the airspeed of the aircraft). The reduced airflow for that part of the bomb's trajectory within the bomb bay (about two feet) and the difference in direction of airflow because of circulation around the aircraft are neglected. The application of this theory in computations involving various bombs and a wide range of release conditions is discussed in this report. Once the first maximum pitch of the bombs is known one can then attempt to predict the effect on range due to this pitch. The range effect due to the moderate values of first maximum pitch observed for the Mk 81 and Mk 82 bombs released from the AD aircraft in a dive has been successfully determined. (See reference 5.) A study is now under way to determine whether this procedure can be used to compute the effects on the range of low drag bombs released under more severe conditions from A3D aircraft.

DESCRIPTION OF MATERIAL

Bombs

The physical characteristics of the Mk 81 and Mk 82 low drag bombs, and the other bombs in the low drag bomb family (for which the results given in this report are also applicable) are given in Table 1. The weights and center of gravity positions of the individual Mk 81 and Mk 82 low drag bombs considered in this report are given in Appendix A, Tables 2 through 5. The Low Drag General Purpose Bombs, Mk 81, Mk 82, Mk 83 and Mk 84, with nose fuze plugs, and the Low Drag Practice Bombs Mk 86, Mk 87 and Mk 88 incorporate the general features of the Douglas Low Drag Bomb Shape. (The nose fuze plug is designed for use with the electric fuzes now under development for the low drag general purpose bombs.) When the AN/M-103A1 mechanical nose fuze is used it replaces the ogival nose fuze plug and changes the bomb's configuration and center of gravity position markedly (see Appendix A). The low drag practice bombs can be filled with either water or wet sand, but do not have fuzing capabilities.

TABLE 1

PHYSICAL DIMENSIONS OF THE LOW DRAG BOMB FAMILY

Bomb Type	Nominal Weight (lb)	Length (in.)	Diameter (in.)	Transverse Moment of Inertia[2] (slugs-ft^2)	Ejection Cartridges Used In Studies	Ejection Velocity (ft/sec)	Center of Gravity[3] (in.)	Moment Arm[4] (in.)
Mk 81 (nose plug or fuze)[1]	250	76.1	9.00	15.15	(2) Mk 2 Mod 0	19.4	3.5-5.5	5.5-3.5
Mk 82 (nose plug or fuze)[1]	500	90.9	10.75	39.06	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	22.4	3.5-5.5	5.5-3.5
Mk 83 (nose plug or fuze)[1]	1000	118.8	14.00	104.57	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	17.3	2-6	7-3
Mk 84 (nose plug or fuze)[1]	2000	154.0	18.00	360.90	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	12.6	11.5-12.5	7.5-6.5
Mk 86 (water filled)	141	76.1	9.00	6.82	(2) Mk 2 Mod 0	24.0	7.5-8.5	1.5-0.5
Mk 86 (wet sand filled)	217	76.1	9.00	8.96	(2) Mk 2 Mod 0	20.5	7-9	2-1
Mk 87 (water filled)	221	90.9	10.75	12.05	(2) Mk 2 Mod 0	20.5	7.5-9.5	1.5-0.5
Mk 87 (wet sand filled)	333	90.9	10.75	16.89	(2) Mk 2 Mod 0	17.2	5.5-6.5	3.5-2.5
Mk 88 (water filled)	458	118.8	14.00	36.76	(2) Mk 2 Mod 0	15.1	7.5-9	1.5-0
Mk 88 (wet sand filled)	783	118.8	14.00	60.31	(1) Mk 2 Mod 0 (1) Mk 1 Mod 2	19.0	6-8	3-1

[1] All values listed, except length, are applicable to either the fused or non-fuzed version. The length given in the table is for the bomb with nose fuse plug; while the lengths of the bombs with the AN/M-103A1 mechanical nose fuze (and appropriate tail fuse) are as follows: Mk 81 - 74.1 in, Mk 82 - 86.9 in, Mk 83 - 116.0 in and Mk 84 - 151.5 in. Individual dimensions are given in Tables 2-5, Appendix A.

[2] Measured through the center of gravity.

[3] Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

[4] The distance measured from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A bomb ejector foot.

The fins of all of the above bombs are nominally canted 2.0 degrees in the direction that will cause the bomb to spin clockwise as viewed from the rear. All bombs except the Mk 84 are equipped with two suspension lugs 14 inches apart and a hoisting lug midway between the suspension lugs. The Mk 84 bomb is equipped with two suspension lugs which are 30 inches apart.

Bomb Rack

The Douglas Aero 7A 4-hook bomb ejector rack combines, in a single lightweight unit, a 14-inch 2-hook rack and a 30-inch 2-hook rack, each type employing a cartridge actuated ejector. The rack uses a piston type ejector foot, mounted 3.5 inches aft of the mid-point between the lug hooks, which was designed to produce a large tail-down moment and, consequently, safe separation of special weapon stores.

During the tests considered in this report the Aero 7A bomb ejector rack was fitted with two Mk 2 Mod 0 cartridges for ejection of the 250 pound Mk 81 bomb and one Mk 2 Mod 0 and one Mk 1 Mod 2 cartridge for the 500 pound Mk 82 bomb. The theoretical predictions of first maximum pitch, reported herein are based on a release from the Aero 7A rack equipped with (1) two Mk 2 Mod 0 cartridges for bombs weighing less than 500 pounds and (2) one Mk 2 Mod 0 and one Mk 1 Mod 2 cartridge for bombs weighing 500 pounds or more.

The ejection velocity was obtained for each bomb-ejector cartridge combination from the BUAER Ejection Velocity Chart (see Figure 1), Appendix A, and scaled proportionately on the basis of data obtained at the Naval Weapons Laboratory during ground ejection tests of a cylindrical body equivalent (in weight) to the Mk 81 low drag bomb (see reference 6). The BUAER Ejection Velocity Chart indicates an expected 25.5 feet per second ejection velocity when two Mk 2 Mod 0 cartridges are used for ejection of the 250 lb Mk 81 bomb, while an ejection velocity of 19.4 feet per second was observed in limited ground tests conducted at the Naval Weapons Laboratory. (Additional ground tests, the results of which are unpublished, yielded further information which tends to validate the scaled data.)

PROCEDURE

Low Drag Bombs Mk 81 and Mk 82 were released from A3D-1 and A3D-2 type airplanes in joint NATC-NWL tests conducted during the period 31 August 1956 through 16 July 1957. Detailed test conditions are given in Tables 2 through 5, Appendix A. A summary of these test conditions is given below:

Type Bomb	Fuze Configuration	Upper Figure-Number of Bombs Tested / Lower Figure-Nominal True Airspeed (kt)			Avg. First Max. Observed Pitch (deg)		
		11	4	2			
Mk 81	Nose Plug	250	390	500	61	54	46
		8					
Mk 81	AN/M-103A1	250			46		
		3	7	5			
Mk 82	Nose Plug	270	380	490	56	40	34
		8	1	4			
Mk 82	AN/M-103A1	230	320	470	57	38	30

The test equipment used in these tests was similar to that described in reference 7 except that in some instances the tracking cameras were fitted with a 48 inch focal length Thompson lens with a doubler that gave an effective focal length of 96 inches.

The yaw histories were computed for each bomb tested from measurements of the apparent attitude of the bomb axis in successive ground camera photographs. The first maximum pitch (total yaw during the first few seconds of flight was confined almost entirely to the vertical plane) in every case was tail downward, and is given for each bomb in Tables 2 through 5, and Figures 2 and 3, Appendix A.

The method used in computing the data above is essentially that given in reference 7 except that in this case the computations are based on the camera records from only one station with the assumption that the total yaw of the bomb was exactly confined to a vertical plane.

The theoretical first maximum pitch due to the ejection force imparted by the Aero 7A ejector foot was computed for each bomb tested using the formulae given in Appendix B which assumes that (a) tne air stream through which the bomb falls is unaffected by the presence of the airplane and (b) the aerodynamic restoring and damping moments are linear functions of the angle of attack. Values of -3.8 and -165.0 were used for the areodynamic parameters $C_{m\alpha}$ (the restoring moment coefficient) and C_{mq} (the damping moment coefficient), respectively, for all test conditions. The individual release conditions and center of gravity positions of each bomb and the average weight and moment of inertia of the bombs were used in the computations.

A comparison of the theoretical and observed first maximum pitch is presented in Tables 2 through 5, Appendix A, and in Figures 4 through 6, Appendix A.

A large percentage of the Mk 81 and Mk 82 bombs released from the A3D airplane had bad flight (see reference 2). Some of these bombs had large total yaw (referring to that angle between the velocity vector and the axis of the bomb) throughout their trajectories while others exhibited this behaviour for a relatively short time (from 3 to 12 seconds). In all instances, where the information could be obtained, the large total yaw was found to have occurred during a time when the spin and yaw rates of the bombs were equal. There is no apparent correlation between the relatively small variations in the magnitude of the first maximum pitch of the bombs at a given release condition and the bad flight (see Figures 2 through 6, Appendix A). Therefore, the first maximum pitch for the bombs which had bad flight will not be excluded in the comparison of observed and computed first maximum pitch in this report. There is no apparent correlation between the magnitude of the first maximum pitch and bomb rack position in the bomb bay (see Figures 4 and 5, Appendix A). Rack position, therefore, will not be considered in the analysis reported herein.

RESULTS

It is evident that a difference of approximately 15 degrees exists (see Figure 2, Appendix A) when a comparison is made between the magnitude of the observed first maximum pitch of the Mk 81 bomb with nose fuze plug and that of the Mk 81 bomb with the AN/M-103A1 mechanical time fuze. This difference is due to the change in the length of the moment arm for the Mk 81 bomb (about 1.5 inches less on the average for the bomb with fuse than for the bomb with nose fuze plug, see Tables 2 and 3, Appendix A, and Figure 7 of Appendix C). No difference is noted between the magnitude of the observed first maximum pitch of the Mk 82 bomb with nose fuze and that of the Mk 82 bomb with nose fuze plug although in this case the average difference in the length of the moment arm was 0.8 inch. The data of Figure 8, Appendix C, show that this difference in moment arm would lead to a difference in first maximum pitch of 6 to 10 degrees over the conditions of the subject test. The experimental data at low values of dynamic pressure fail to show this difference but at the higher values of Q the bombs with nose plug generally have a larger value of pitch, as expected.

The theoretical calculations of first maximum pitch for the Mk 82 bomb with nose fuze plug and with AN/M-103A1 mechanical nose fuze are in very good agreement with the observations (see Figures 5 and 6). In view of the accuracy of the observed first maximum pitch (in general about ±3 to 5 degrees) the above comparison for the Mk 82 low drag bomb is considered satisfactory.

The comparison of the theoretical first maximum pitch with the values observed for the Mk 81 bombs indicates that the theoretical values agree with those observed in the region of dynamic pressure of 5000 lb/ft-sec^2. At larger values of dynamic pressure the theoretical and measured values fail to match by 10 to 20 degrees. It is believed that this much discrepancy is acceptable but a final answer on this point cannot be obtained until the sensitivity of the impact point of the bomb to the magnitude of the first maximum pitch is determined.

Since the theoretical values of first maximum pitch appear to match the observed values satisfactorily (for the range of release conditions tested) it is believed that this method can be used to predict the first maximum pitch of other bombs under certain conditions, thus eliminating the necessity of actually testing at numerous release conditions. The predictions should be limited to bombs which (a) are ejected with similar or larger ejection velocities, (b) have an angular velocity not exceeding 300 degrees per second, and (c) have similar or larger ratios of weight to product of length and diameter in order to avoid conditions where the lift forces due to the local air stream about the aircraft may become important. Predictions of initial pitch greater than the value of 70 degrees made under the test conditions reported herein may be invalid because the assumption of free stream flow may no longer be satisfactory when the bomb has very large initial angular rate. (Data for bombs ejected with smaller velocities are now being obtained and will be analyzed as soon as they become available.)

Information on the initial pitch is of value in the computation of ballistic tables since it can be used in computing the effect on range due to launching phenomena. As a result of an investigation reported in reference 5 it has been concluded that satisfactory results can be obtained (assuming that the necessary aerodynamic data are available) by using this method, at least for the moderate values of initial yaw (15 to 30 degrees) observed for bombs released from the AD aircraft in dive. A study of the accuracy of the prediction of range effects for the more severe conditions discussed in this report is under way. The computed theoretical first maximum pitch for various low drag bombs is given in Appendix C, Tables 6 through 15 and Figures 7 through 16. Each table and figure covers the operational limitations of the A3D type airplane with respect to altitude and airspeed. It should be noted that the accuracy of the data for the water filled Mk 86, Mk 87 and Mk 88 bombs, which have smaller weight to longitudinal cross section area ratios than the Mk 81 and Mk 82 bombs, is subject to question. Although the Mk 84 bomb has smaller ejection velocity than the bombs tested, the accuracy of the data is probably adequate because of its higher ratio of weight to cross sectional area.

CONCLUSIONS

Based on the results obtained in the comparison of observed and theoretical first maximum pitch for the Mk 81 and Mk 82 low drag bombs it is concluded that:

a. The theoretical solution assuming free stream conditions and linear aerodynamic moments is a satisfactory method of predicting first maximum pitch for the conditions under which the test data were obtained.

b. The difference between the observed first maximum pitch of the Mk 81 bomb with nose plug and that of the Mk 81 bomb with nose fuze is due to the difference in the positions of center of gravity which results in the bombs being ejected with different angular rates.

c. There is no apparent correlation between the magnitude of the first maximum pitch and the location of the bomb rack in the bomb bay.

d. There is no apparent difference between the magnitudes of the first maximum pitch of those bombs that had bad flight and those bombs that had good flight (when released at the same conditions).

In addition, it is believed that the theoretical free stream solution developed herein will satisfactorily predict the first maximum pitch of other low drag bombs ejected from the A3D airplane by the Aero 7A bomb rack provided that (a) the ejection velocity of the bombs is at least 10 feet per second, (b) the angular velocity of the bombs at release does not exceed 300 degrees per second, and (c) the ratio of weight to longitudinal cross section area of the bombs is no smaller than that of the subject bombs.

FUTURE PLANS

The effect on range due to first maximum pitch of Mk 81 and Mk 82 bombs is being determined by the computation of trajectories. If these ranges satisfactorily match the observed ranges (see reference 2), it is planned to incorporate into the computations of ballistic tables corrections for the effect on range due to first maximum pitch.

Ballistic data are now being obtained on the Mk 83 low drag bomb with the AN/M-103A1 mechanical nose fuze and with nose fuze plug, and the Mk 84 low drag bomb with nose fuze plug. With these data and the results of previous tests of the Mk 83 bomb reported in reference 8, further comparison of observed and theoretical first maximum pitch will be made.

REFERENCES

1. E. L. Scherich, Applicability of Ballistic Data for Low Drag Bombs Mk 81, Mk 82 and Mk 83 Released in Horizontal Flight to These Bombs Released in Dive, NPG Conf Report No. 1579 of 7 February 1958
2. J. J. Madden, Separation and Free Flight Tests of 250-lb Mk 81 and 500-lb Mk 82 Low Drag G. P. Bombs with Nose Fuze Plug Released from A3D-1 Aircraft, NPG Conf Report No. 1600 of 27 May 1958
3. J. D. Kunlo, Improvement of the Separation of Low Drag Bombs from the A3D Aircraft, NPG Conf Tech Memo No. K-19/58 of December 1958
4. Armament Material Bulletin No. 260, AER-AU-202 of 1 March 1959
5. D. M. Silvestrucci, Comparison of Computed and Measured Range Effects of the Initial Yaw of Bombs, NPG Tech Memo No. K-20/58 of November 1958
6. R. J. Anderle, Laboratory Tests of Reduced Charge Cartridges for the Aero 7A Ejector Rack, NPG Tech Memo No. K-5/59 of March 1959
7. C. H. Wingo, Jr. and F. L. Jones, Free Flight and Catapult Tests of 250-lb Low Drag G. P. Bombs Types EX 2 Mod 2 and EX 2 Mod 2A, 250-lb Low Drag Fragmentation Bomb Type EX 17 Mod 6, 2000-lb Low Drag G. P. Bomb Type EX 11 Mod 1 with Canted Fins, NPG Conf Report No. 1419 of 17 October 1955
8. E. R. Tharp, Separation and Free Flight Characteristics of the 1000-lb Low Drag G. P. Bomb Mk 83 Released from the A3D-2 Aircraft in Horizontal Flight, NPG Tech Memo No. K-8/58 of June 1958

APPENDIX A

BUAER EJECTION VELOCITY CHART

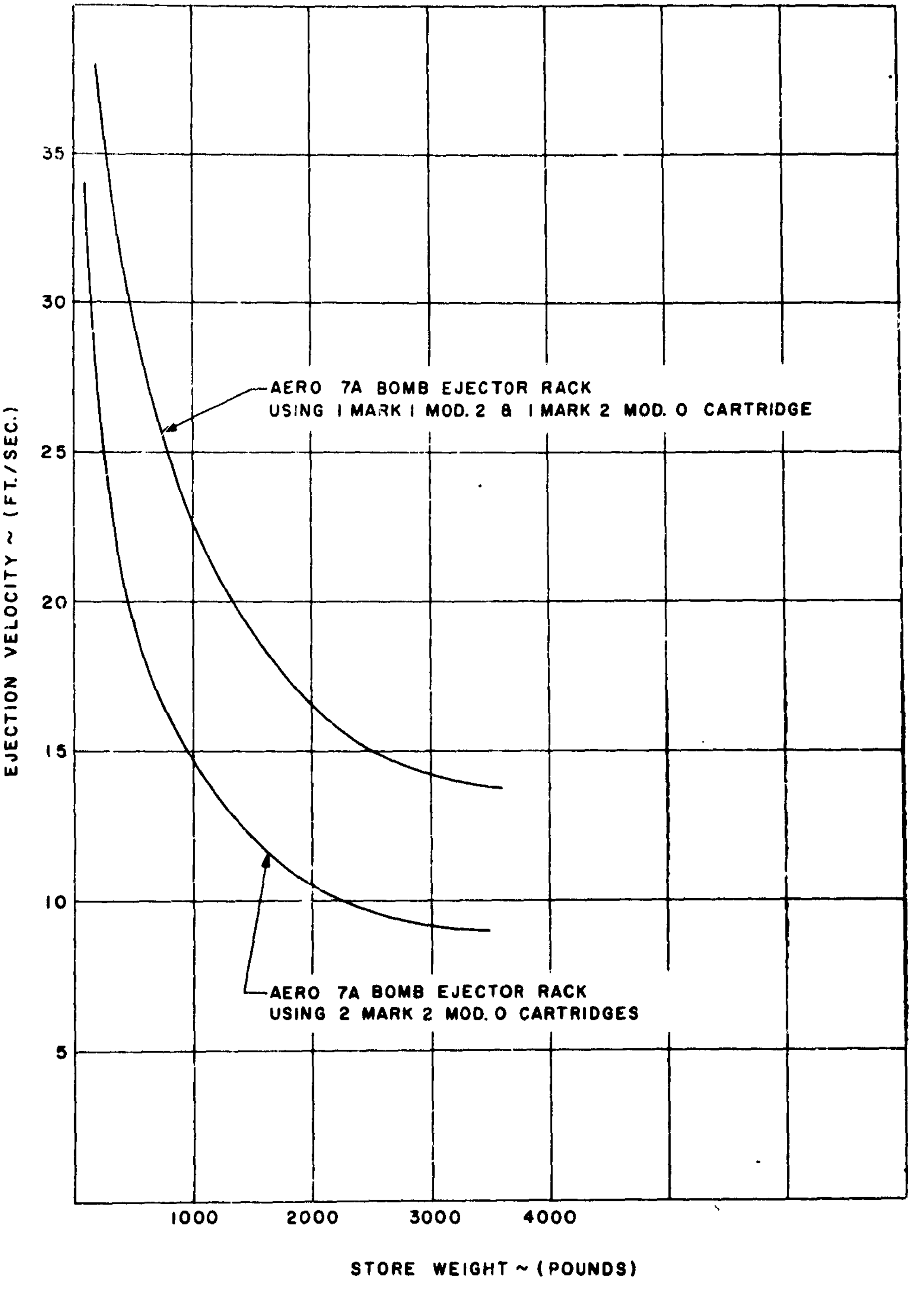


FIGURE 1

TABLE 2

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 250 LB
MK 81 MOD 1 LOW DRAG BOMB FITTED WITH NOSE FUZE PLUG

NWL Assigned Bomb Number	Date of Drop	Drop Number	Time of Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure[1] X10^{-3} (lb/ft-sec^2)	Bomb Weight[2] (lb)	Center of Gravity[3] (in.)	Moment Arm[4] (in.)	Rack Position[5]	First Maximum Pitch Observed[6] (deg)	First Maximum Pitch Theoretical[7] (deg)	Difference First Maximum Pitch[8] (deg)
70	14 Mar 1957	4	[illegible]	[illegible]	219	4.2	250	3.[illegible]	5.4	2F	61[9]	66	-5
68	14 Mar 1957	2	1359	7590	228	4.5	255	3.5	5.5	3F	66	65	1
69	14 Mar 1957	3	1400	7600	228	4.5	249	3.6	5.4	4F	60	64	-4
73	10 Jul 1957	1	0950	10340	250	5.0	254	3.5	5.5	3F	73	63	10
77	10 Jul 1957	5	1047	10310	252	5.1	248	3.4	5.6	1F	63	63	0
75	10 Jul 1957	3	1032	10230	252	5.1	246	3.5	5.5	2F	70	62	8
84	10 Jul 1957	14	1328	10310	253	5.1	250	4.0	5.0	1A	55	56	-1
89	10 Jul 1957	20	1617	10330	254	5.2	244	3.6	5.4	1A	54	61	-7
78	10 Jul 1957	6	1057	10330	258	5.3	253	3.5	5.5	1A	52	63	-11
76	10 Jul 1957	4	1040	10330	262	5.5	250	3.5	5.5	2A	59	59	0
88	10 Jul 1957	19	1611	10290	265	5.6	248	3.6	5.4	1F	61	58	3
81	10 Jul 1957	11	1306	10290	385	11.8	252	4.0	5.0	2F	58	37	21
82	10 Jul 1957	12	1313	10290	385	11.8	236	5.0	4.0	2A	52	29	23
79	10 Jul 1957	9	1252	10320	389	12.0	250	3.8	5.2	3F	57[9]	39	18
83	10 Jul 1957	13	1321	10230	404	13.1	240	5.0	4.0	1F	49	28	21
85	10 Jul 1957	16	1552	10160	504	20.3	247	3.5	5.5	3F	47	31	16
87	10 Jul 1957	18	1601	10160	504	20.3	240	3.5	5.5	2A	45[9]	31	14

[1]Dynamic Pressure = $Q = 1/2\ \rho V^2$ where ρ = standard density at altitude and V = true airspeed

[2]Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

[3]Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

[4]Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

[5]Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-outboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

[6]Obtained from observed test data.

[7]Obtained from theoretical free stream equation solution.

[8]Observed first maximum pitch minus theoretical first maximum pitch.

[9]Bombs which exhibited bad flight.

TABLE 3

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 250 LB
MK 81 MOD 1 LOW DRAG BOMB FITTED WITH AN/M-103A1 MECHANICAL NOSE FUZE

NWL Assigned Bomb Number	Date of Drop	Drop Number	Time of Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure[1] X10^{-3} (lb/ft-sec^2)	Bomb Weight[2] (lb)	Center of Gravity[3] (in.)	Moment Arm[4] (in.)	Rack Position[5]	First Maximum Pitch Observed[6] (deg)	First Maximum Pitch Theoretical[7] (deg)	Difference First Maximum Pitch[8] (deg)
71	14 Mar 1957	5	1425	7500	218	4.1	259	5.1	3.9	1F	53	48	5
72	21 Mar 1957	1	1534	3960	229	5.1	245	5.0[10]	4.0[10]	3A	43	45	- 2
64	11 Mar 1957	5	1735	10320	257	5.3	252	5.0	4.0	3F	47	44	3
63	11 Mar 1957	4	1540	10210	261	5.4	248	4.8	4.2	1F	45	46	- 1
61	11 Mar 1957	2	1512	10250	266	5.7	257	5.0	4.0	4F	40	43	- 3
60	11 Mar 1957	1	1506	10320	269	5.8	247	5.0	4.0	3F	45	42	3
62	11 Mar 1957	3	1530	10230	269	5.8	249	5.1	3.9	2F	47	42	5
65	11 Mar 1957	6	1742	10270	272	5.9	252	5.0	4.0	4F	49[9]	42	7

[1]Dynamic Pressure = $Q = 1/2\ \rho V^2$ where ρ = standard density at altitude and V = true airspeed.

[2]Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

[3]Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

[4]Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

[5]Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-outboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

[6]Obtained from observed test data.

[7]Obtained from theoretical free stream equation solution.

[8]Observed first maximum pitch minus theoretical first maximum pitch.

[9]Bombs which exhibited bad flight.

[10]Center of gravity position, and therefore, moment arm unknown. Average values of 5.0 inches and 4.0 inches, respectively, were used in the theoretical calculations.

TABLE 4

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 500 LB
MK 82 MOD 1 LOW DRAG BOMB FITTED WITH NOSE FUZE PLUG

NWL Assigned Bomb Number	Date of Drop	Drop Number	Time of Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure[1] X10-3 ($lb/ft-sec^2$)	Bomb Weight[2] (lb)	Center of Gravity[3] (in.)	Moment Arm[4] (in.)	Rack Position[5]	First Maximum Pitch: Observed[6] (deg)	First Maximum Pitch: Theoretical[7] (deg)	Difference First Maximum Pitch[8] (deg)
56	16 Jul 1957	4	1010	10430	264	5.5	500	3.6	5.4	2A	59[9]	65	- 6
55	16 Jul 1957	3	1005	10400	266	5.6	501	4.1	4.9	2F	56[9]	58	- 2
61	16 Jul 1957	11	1642	10300	274	6.0	497	4.3	4.7	3F	54[9]	55	- 1
11	5 Sep 1956	1	1540	5140	320	9.6	- [11]	4.5[10]	4.5[10]	-[11]	43	41	2
54	16 Jul 1957	2	1000	10350	394	12.4	500	3.6	5.4	3A	43[9]	44	- 1
65	16 Jul 1957	15	1725	10250	393	12.4	496	3.1	5.9	3F	41	47	- 6
57	16 Jul 1957	7	1400	10270	397	12.6	503	3.6	5.4	3F	43	44	- 1
64	16 Jul 1957	14	1711	10230	400	12.8	494	3.8	5.2	2A	42	42	0
12	5 Sep 1956	2	1548	4990	370	12.8	- [11]	4.5[10]	4.5[10]	-[11]	31	35	- 4
16	6 Sep 1956	2	1235	1950	370	14.1	- [11]	4.5[10]	4.5[10]	-[11]	35	33	2
13	5 Sep 1956	3	1553	5010	434	17.8	- [11]	4.5[10]	4.5[10]	-[11]	31	30	1
52	11 Jul 1957	2	1248	10290	510	20.7	503	3.9	5.1	3F	38	32	6
62	16 Jul 1957	12	1650	7120	512	21.0	510	4.1	4.9	3A	32[9]	30	2
53	16 Jul 1957	1	0950	10150	529	22.4	499	4.5	4.5	3F	33	27	6
18	6 Sep 1956	4	1305	1720	466	22.4	- [11]	4.5[10]	4.5[10]	-[11]	38	27	11

[1] Dynamic Pressure = $Q = 1/2\ \rho V^2$ where ρ = standard density at altitude and V = true airspeed.

[2] Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

[3] Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

[4] Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

[5] Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-outboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

[6] Obtained from observed test data.

[7] Obtained from theoretical free stream equation solution.

[8] Observed first maximum pitch minus theoretical first maximum pitch.

[9] Bombs which exhibited bad flight.

[10] Center of gravity position, and therefore moment arm unknown. Average values of 4.5 inches for each were used in the theoretical calculations.

[11] Insufficient data or unknown.

TABLE 5

PHYSICAL DATA AND FIRST MAXIMUM PITCH OF 500 LB
MK 82 MOD 1 LOW DRAG BOMB FITTED WITH AN/M-103A1 MECHANICAL NOSE FUZE

NWL Assigned Bomb Number	Date of Drop	Drop Number	Time of Drop	True Altitude (ft)	True Airspeed (kt)	Dynamic Pressure[1] X10⁻³ (lb/ft-sec²)	Bomb Weight[2] (lb)	Center of Gravity[3] (in.)	Moment Arm[4] (in.)	Rack Position[5]	First Maximum Pitch Observed[6] (deg)	First Maximum Pitch Theoretical[7] (deg)	Difference First Maximum Pitch[8] (deg)
48	14 Mar 1957	6	1650	7040	212	4.0	520	5.3	3.7	3F	58[9]	53	5
50	14 Mar 1957	8	1710	7080	218	4.2	527	4.9	4.1	2F	58	57	1
49	14 Mar 1957	7	1656	7090	218	4.2	514	4.6	4.4	4F	52	60	-8
51	14 Mar 1957	9	1722	7120	224	4.4	520	4.8	4.2	1F	58	57	1
42	13 Mar 1957	4	1120	10110	246	4.8	512	4.4	4.6	1F	62[9]	60	2
41	13 Mar 1957	3	1114	10140	248	5.0	512	5.6	3.4	2F	47	53	-6
40	13 Mar 1957	2	1106	10080	248	5.0	502	4.8	4.2	4F	53	54	-1
39	13 Mar 1957	1	1100	10110	253	5.1	498	4.6	4.4	3F	68[9]	55	13
15	6 Sep 1956	1	1228	1940	317	10.3	-[11]	4.5[10]	4.5[10]	-[11]	38	38	0
17	6 Sep 1956	3	1243	1380	415	18.0	-[11]	4.5[10]	4.5[10]	-[11]	27	29	-2
45	13 Mar 1957	6	1342	10260	481	18.4	517	5.5	3.5	4F	30[9]	23	7
44	13 Mar 1957	5	1335	10250	492	19.3	511	5.3	3.7	3F	32	25	7
47	13 Mar 1957	8	1403	10200	497	19.8	512	4.6	4.4	1F	31[9]	28	3

[1]Dynamic Pressure = $Q = 1/2\, \rho V^2$ where ρ = standard density at altitude and V = true airspeed.

[2]Individual bomb weights are listed although nominal weights of 250 pounds and 500 pounds were used for the Mk 81 and Mk 82 bombs, respectively, for calculation of the individual theoretical first maximum pitch.

[3]Distance aft of a point on the bomb axis directly under the center of the forward suspension lug.

[4]Distance from the center of gravity of the bomb to a point on the bomb axis directly under the forward edge of the Aero 7A rack bomb ejector foot.

[5]Bomb location in the bomb bay where F = forward station 319.825 inches (from the airplane nose) and A = aft station 415.195 inches (from the airplane nose) and 1, 2, 3, and 4 are positions port-inboard, port-inboard, starboard-inboard, and starboard-outboard, respectively.

[6]Obtained from observed test data.

[7]Obtained from theoretical free stream equation solution.

[8]Observed first maximum pitch minus theoretical first maximum pitch.

[9]Bombs which exhibited bad flight.

[10]Center of gravity position, and therefore moment arm unknown. Average values of 4.5 inches for each were used in the theoretical calculations.

[11]Insufficient data or unknown.

250-LB MK 81 MOD I LOW DRAG G. P. BOMB

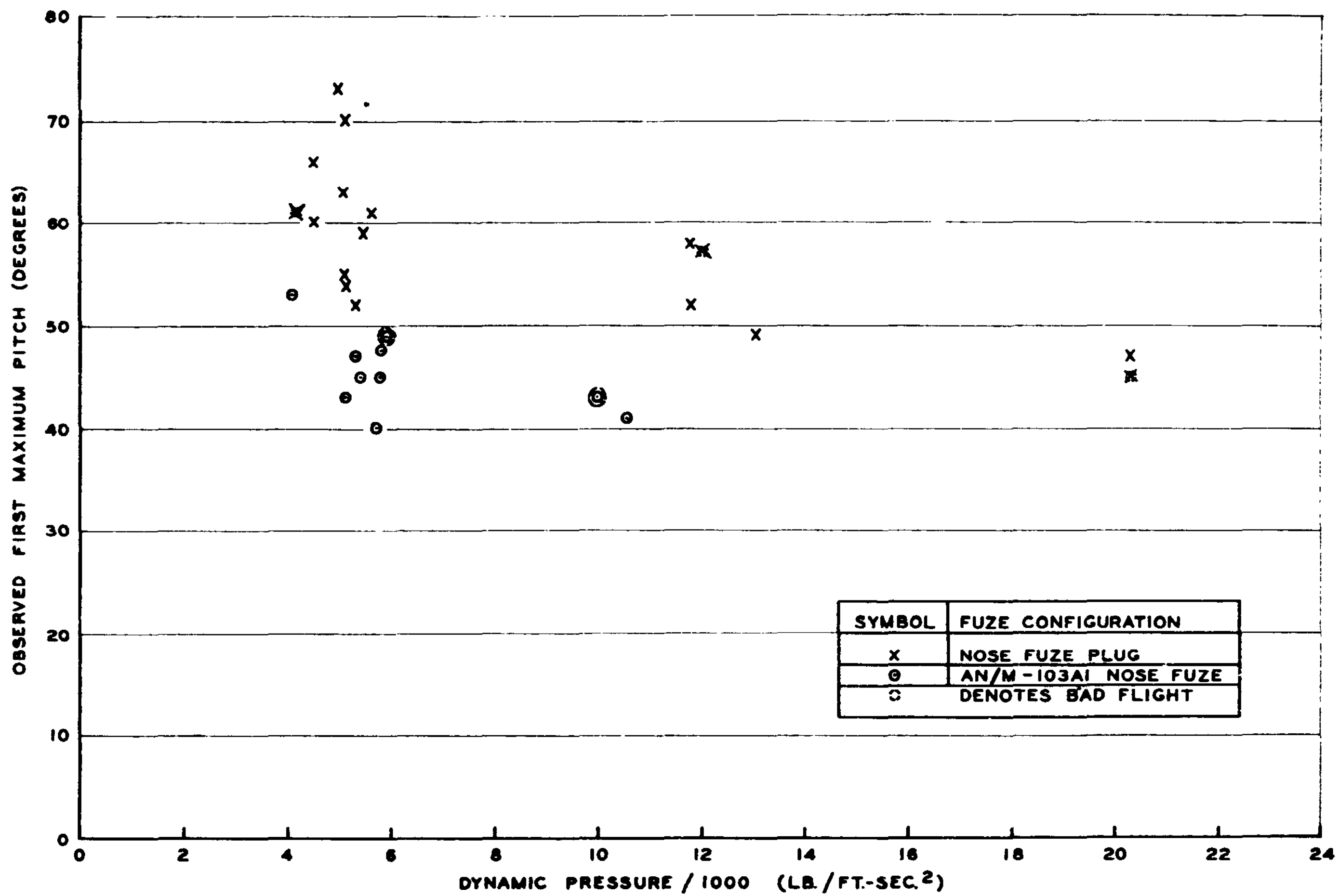


FIGURE 2

500-LB MK 82 MOD I LOW DRAG G. P. BOMB

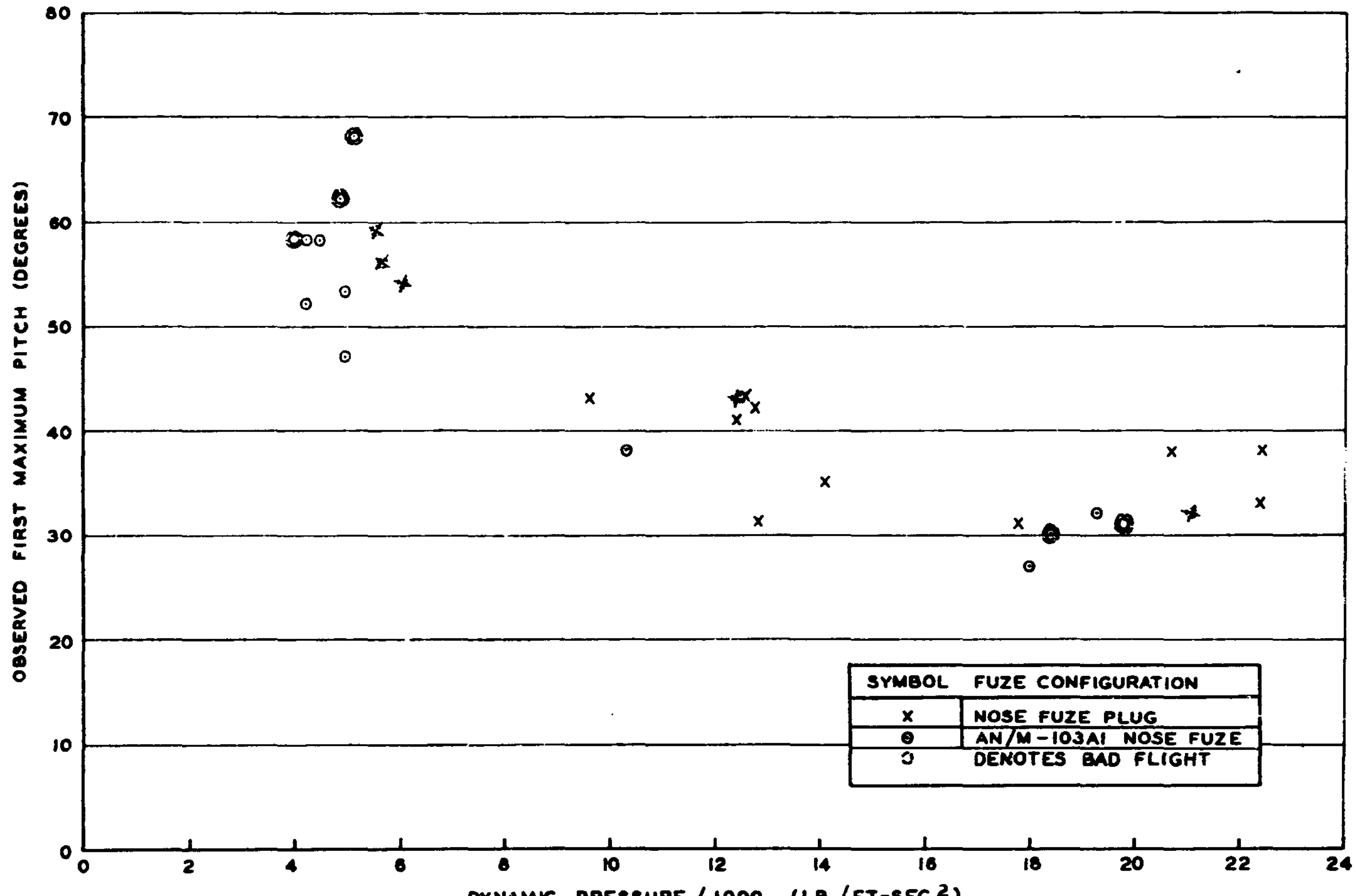


FIGURE 3

250-LB MK 81 MOD I LOW DRAG G. P. BOMB

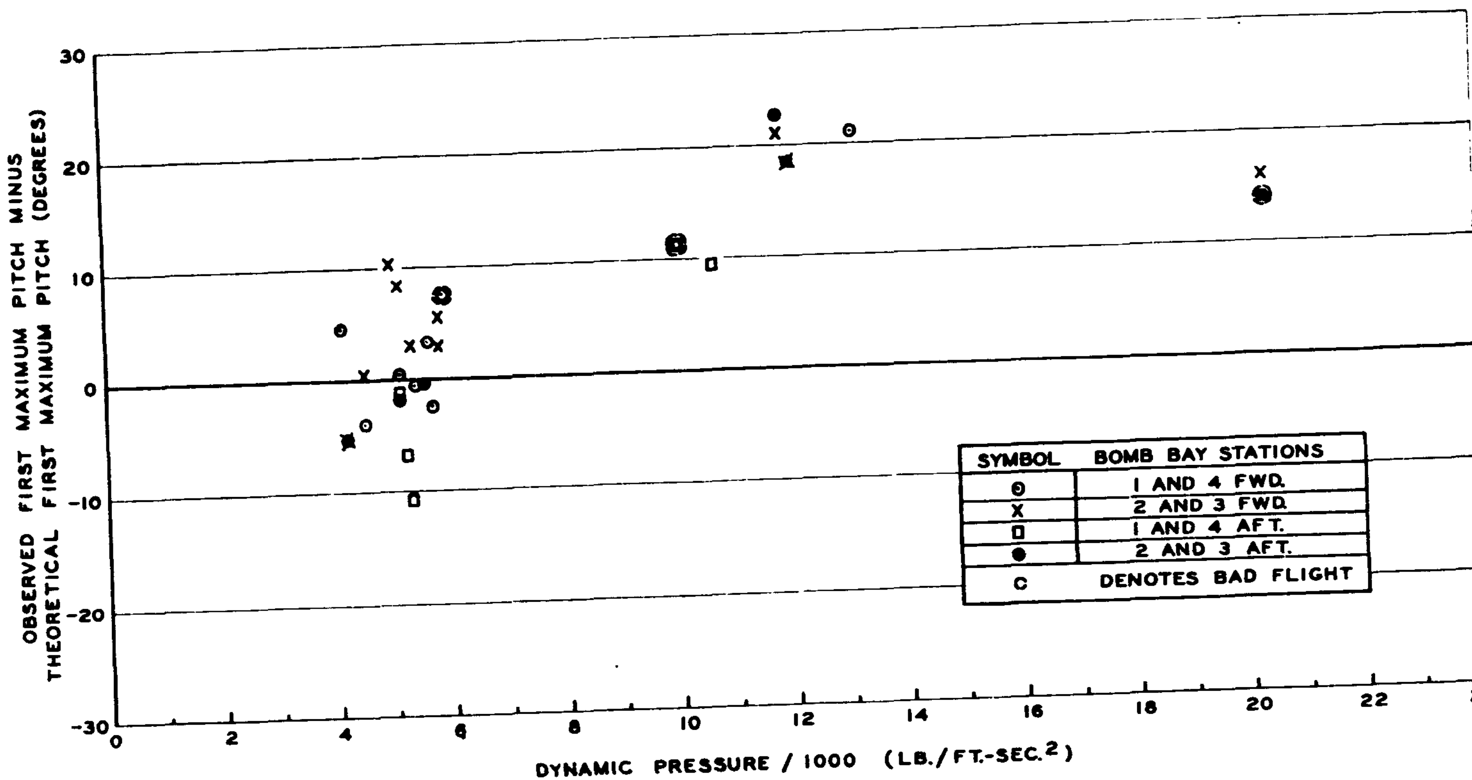


FIGURE 4

500-LB MK 82 MOD I LOW DRAG G. P. BOMB

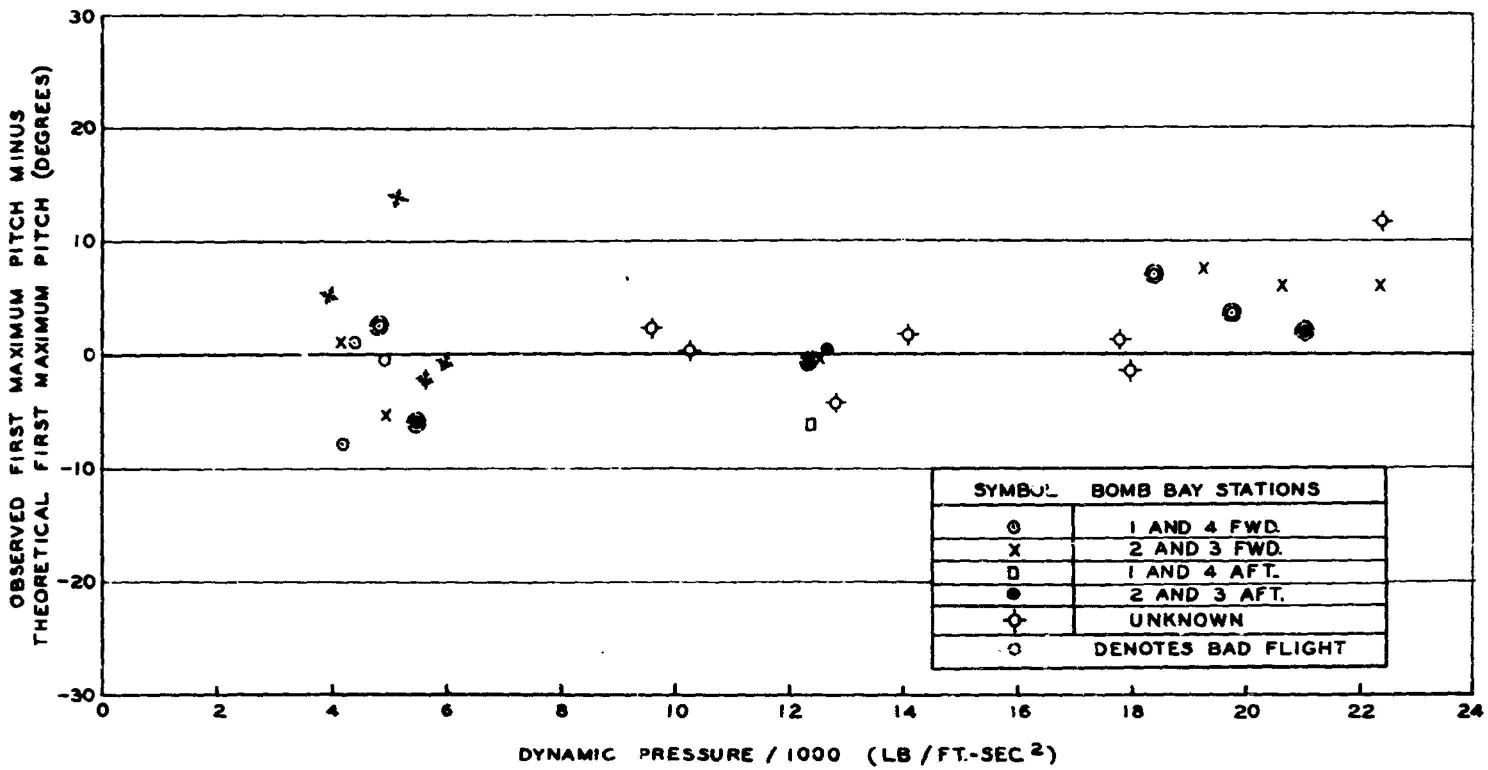


FIGURE 5

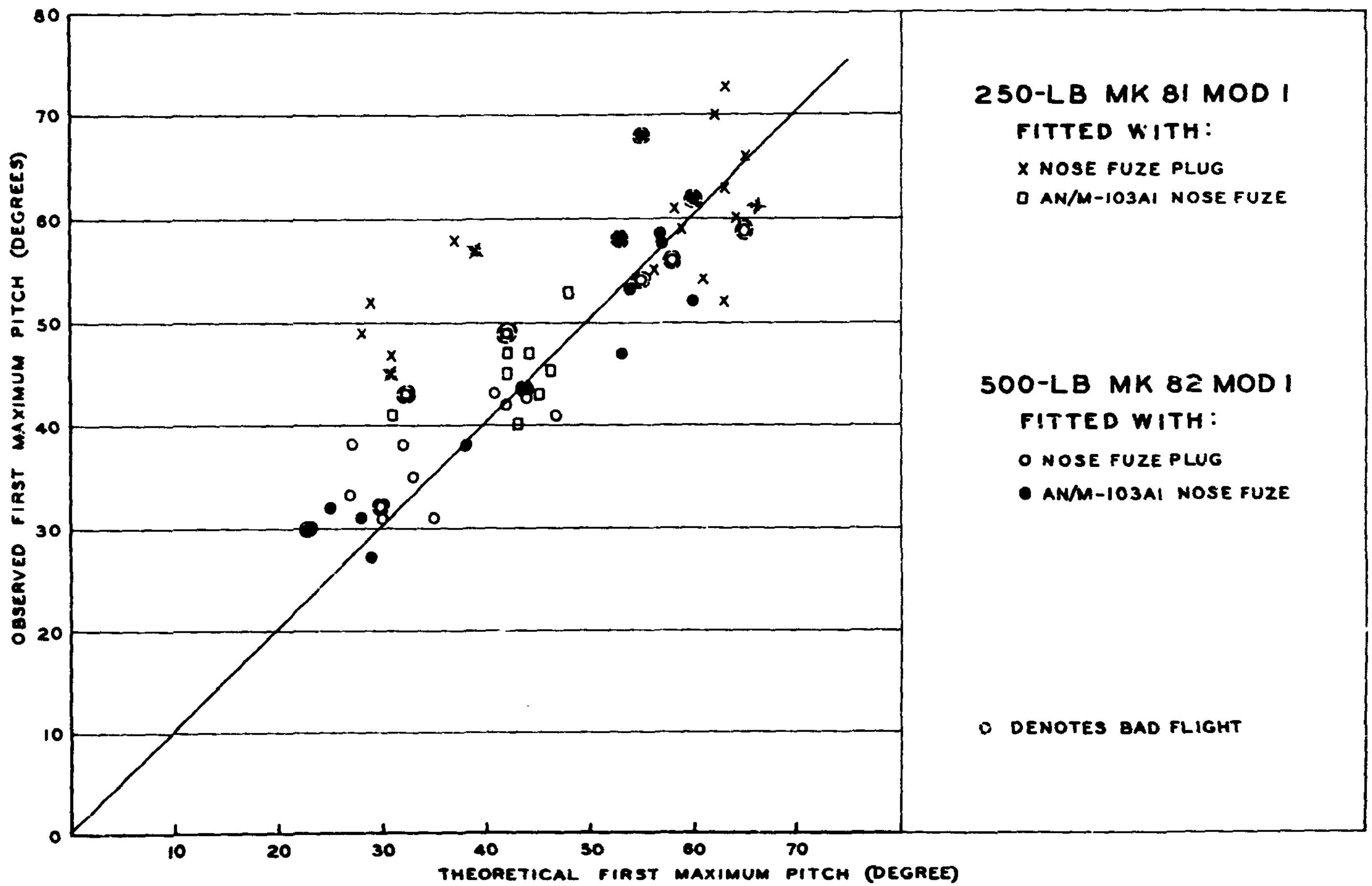

80
70
60
50
40
30
20
10
0
OBSERVED FIRST MAXIMUM PITCH (DEGREES)
10
20
30
40
50
60
70
THEORETICAL FIRST MAXIMUM PITCH (DEGREE)
250-LB MK 81 MOD I
FITTED WITH:
X NOSE FUZE PLUG
□ AN/M-103AI NOSE FUZE
500-LB MK 82 MOD I
FITTED WITH:
○ NOSE FUZE PLUG
● AN/M-103AI NOSE FUZE
○ DENOTES BAD FLIGHT

FIGURE 6

APPENDIX B

DERIVATION OF THE EQUATION USED TO CALCULATE FIRST MAXIMUM PITCH

The ejection force of the launcher is assumed to be constant through the ejection stroke and to have a value which would produce the ejection velocity measured in static tests (in the static tests the launcher was placed on its side and hence "gravity free" values of velocity were obtained). The aerodynamic restoring and damping moments were assumed to be a linear function of angle of attack. The bomb had no appreciable spin. The value of angle of attack at the end of the ejector stroke was calculated for the extreme test conditions, was found to be small (less than five degrees) and is neglected in the derivation.

The acceleration, a, due to the ejection force is approximated by the following equation:

$$a = E_j^2/2\ell,$$

where E_j = the vertical velocity, obtained at the end of the ejector stroke, which would be produced in a gravity free situation.

ℓ = the length of the ejection stroke (0.533 feet).

For bombs ejected from aircraft flying horizontally, the vertical acceleration of the center of gravity, $\ddot{y}$, is

$$\ddot{y} = a + g = \frac{E_j^2}{2\ell} + g$$

The ejection time, t_{ej}, is given by

$$t_{ej} = \left(\frac{2\ell}{a}\right)^{1/2} = 2\ell/(E_j^2 + 2\ell g)^{1/2}$$

where ℓ is the value of y at the end of the ejection stroke.

The angular acceleration of the bomb body, $\ddot{\alpha}_{ej}$ during ejection, is approximated by

$$I\ddot{\alpha}_{ej} = dma$$

$$\text{or} \quad \ddot{\alpha}_{ej} = \frac{dm\, E_j^2/2\ell}{I}$$

where d = the moment arm, i.e., the distance from the bomb's center of gravity to a point on the bomb axis directly under the forward edge of the bomb ejector foot,

m = the mass of the bomb, and

I = the transverse moment of inertia measured through the bomb's center of gravity.

Then the angular velocity of the bomb at the end of the ejection stroke

$$\dot{\alpha}_{ej} = \frac{dmE_j^2}{I2\ell} \cdot t_{ej} = \frac{dmE_j^2}{I}\left(\frac{1}{(E_j^2 + 2\ell g)}\right)^{1/2}$$

The angle of attack of a bomb, assuming linear theory, is

$$\alpha = K_1 e^{(\lambda_1 + i\omega_1)t} + K_2 e^{(\lambda_2 + i\omega_2)t}$$

If spin can be neglected (since it is negligible during the first maximum pitch), the ω_1 is equal to $-\omega_2$, while λ_1, is equal to λ_2. Making these substitutions, neglecting the value of angle of attack at the end of the ejector stroke, and evaluating the constants of integration K_1 and K_2,

$$\alpha = \frac{\dot{\alpha}_{ej}}{\omega} \sin \omega t \; e^{\lambda t}$$

where ω = the pitch rate (radians/sec) $= \frac{V}{2b}\left(\frac{-C_{m\alpha}\ \pi\rho_h b^5}{2\ I}\right)^{1/2}$

and λ = the pitch damping factor $= \frac{VC_{mq}\ \pi\rho_h b^4}{32I}$

where $C_{m\alpha}$ = the restoring moment coefficient,

C_{mq} = the damping moment coefficient,

V = the true airspeed,

b = the diameter of the bomb,

ρ_h = the density at altitude "h".

The magnitude of the pitch at the end of a quarter cycle, α_m, is given by

$$\alpha_m = \frac{dmE_j^{\,2}}{I(E_j^{\,2} + 2\ell g)^{1/2}\omega}\ e^{\frac{\pi\lambda}{2\omega}}$$

APPENDIX C

TABLE 6

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

250-lb Mk 81 Mod 1 Low Drag G. P. Bomb

Upper Figure
3.5 In. Moment Arm

Center Figure
4.5 In. Moment Arm

Lower Figure
5.5 In. Moment Arm

True Airspeed (Knots)

ALTITUDE ABOVE SEA LEVEL (FEET)	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000		57	43 55 67	39 50 61	35 46 56	33 42 51	30 39 48	28 36 45	26 34 41	24 31 38	23 29 35	21 27 33	19 24 30	17 22 27	16 20 24	14 18 22
10,000		66	50 64	45 58	41 53 65	38 49 60	35 46 56	33 43 52	30 39 48	28 36 45	26 34 42	25 32 39	22 28 35	20 26 31	18 23 28	17 21 26
20,000			59	54 69	49 64	46 59	43 55 67	40 51 63	37 47 57	34 44 53	32 41 50	30 38 47	26 34 41	24 31 37	22 28 34	20 25 31
30,000				65	60	55	51 66	48 62	44 57 69	41 53 64	38 49 60	36 46 56	32 41 50	29 37 45	26 34 41	24 31 38
40,000						69	64	60	55	51 66	48 62	45 58	40 51 63	36 46 57	33 42 51	30 39 47
50,000										66	62	58	51 66	46 60	42 54 66	39 50 61
60,000													66	60	54 69	50 64

TABLE 7

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

500-lb Mk 82 Mod 1 Low Drag G. P. Bomb

Upper Figure: 3.5 In. Moment Arm — Center Figure: 4.5 In. Moment Arm — Lower Figure: 5.5 In. Moment Arm

ALTITUDE ABOVE SEA LEVEL (FEET)	True Airspeed (Knots)															
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000		63	48	43	40	37	34	32	29	27	25	24	21	19	17	16
			61	56	51	47	44	41	38	35	33	31	27	24	22	20
				68	62	57	53	50	46	43	40	37	33	30	27	25
10,000			55	50	46	43	40	37	34	32	30	28	25	22	20	18
				65	59	55	51	47	44	41	38	36	32	28	26	24
						67	62	58	54	50	46	43	39	35	32	29
20,000			66	60	55	51	47	44	41	38	35	33	29	27	24	22
						65	61	57	52	49	46	43	38	34	31	28
								69	64	59	55	52	46	42	38	35
30,000					67	62	57	53	49	46	43	40	36	32	29	27
								69	63	59	55	52	46	41	38	34
											67	63	56	50	46	42
40,000								67	62	57	53	50	45	40	36	33
											69	64	57	52	47	43
													70	63	57	52
50,000											69	65	57	52	47	43
														66	60	55
																68
60,000														66	60	55

TABLE 8

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

1000-lb Mk 83 Mod 2 Low Drag G. P. Bomb

Upper Figure: 3.0 In. Moment Arm
Center Figure: 5.0 In. Moment Arm
Lower Figure: 7.0 In. Moment Arm

ALTITUDE ABOVE SEA LEVEL (FEET)	True Airspeed (Knots)															
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	50	33	25	23	21	19	18	17	15	14	13	12	11	10	9	8
		55	41	38	35	32	30	28	26	24	22	21	19	17	15	14
			58	53	48	44	41	39	35	32	30	29	26	23	21	19
10,000	58	38	29	27	25	23	21	19	18	17	16	15	13	12	11	10
		64	48	43	40	37	34	32	29	27	25	24	21	19	18	16
			68	62	57	53	49	45	42	39	36	34	31	27	25	23
20,000	69	46	35	32	29	27	25	23	22	20	19	17	16	14	13	12
			58	53	49	45	42	39	36	33	31	29	26	23	21	19
					69	63	58	54	50	46	43	41	35	32	29	27
30,000		55	42	39	36	33	30	28	26	24	22	21	19	17	15	14
			70	64	58	54	50	47	43	40	38	35	31	28	25	23
								66	61	57	53	49	44	39	36	33
40,000		66	53	48	44	41	38	35	33	30	28	26	23	21	19	18
						67	62	59	54	50	47	44	39	35	32	29
										70	65	62	55	49	45	41
50,000			68	62	57	52	49	46	42	39	36	34	30	27	25	23
									70	65	60	57	51	46	42	38
														64	59	53
60,000						67	63	59	54	50	47	44	39	35	32	29
													65	59	54	49
																68

TABLE 9

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

2000-lb Mk 84 Mod 1 Low Drag G. P. Bomb

Upper Figure 4.5 In. Moment Arm — Center Figure 5.5 In. Moment Arm — Lower Figure 6.5 In. Moment Arm

ALTITUDE ABOVE SEA LEVEL (FEET)	True Airspeed (Knots)															
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	38	25	19	17	16	15	14	13	12	11	10	10	8	8	7	6
	45	31	23	21	20	18	17	15	14	13	12	12	10	9	8	8
	55	37	27	25	23	21	20	18	17	16	15	14	12	11	10	10
10,000	44	29	22	20	19	17	16	15	14	13	12	11	10	9	8	7
	54	36	27	25	23	21	19	18	17	16	14	13	12	11	10	9
	64	43	32	29	27	25	23	21	20	18	17	16	14	13	12	11
20,000	53	36	27	24	22	20	19	18	16	15	14	13	12	11	10	9
	65	43	33	30	27	25	23	22	20	19	17	16	14	13	12	11
		51	38	35	32	30	27	26	24	22	21	19	17	15	14	13
30,000	65	43	32	29	27	25	23	22	20	18	17	16	14	13	12	11
		53	40	36	33	30	28	26	24	23	21	20	18	16	14	13
		62	47	42	39	36	33	31	29	27	25	23	21	19	17	16
40,000		54	41	37	34	31	29	27	25	23	22	20	18	16	15	14
		66	50	45	41	38	35	33	31	28	26	25	22	20	18	17
			59	53	49	45	42	39	36	33	31	29	26	23	21	20
50,000		70	52	48	44	40	37	35	32	30	28	26	23	21	19	17
			64	58	53	49	46	43	39	37	34	32	28	26	23	21
				69	63	58	54	50	47	43	40	38	34	30	27	25
60,000			67	61	56	52	48	45	42	39	36	34	30	27	25	22
					68	63	59	55	51	47	44	41	37	33	30	27
							70	65	60	56	52	49	43	39	35	32

TABLE 10

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

141-lb Mk 86 Low Drag Practice Bomb (Water Filled)

Upper Figure
0.5 In. Moment Arm

Center Figure
1.5 In. Moment Arm

Lower Figure
2.5 In. Moment Arm

ALTITUDE ABOVE SEA LEVEL (FEET)	True Airspeed (Knots)															
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	12	8	6	6	5	5	4	4	4	3	3	3	3	2	2	2
	36	24	18	16	15	14	13	12	11	10	10	9	8	7	7	6
	60	40	30	27	25	23	21	20	18	17	16	15	14	12	11	10
10,000	15	10	8	7	6	6	5	5	5	4	4	4	4	3	3	3
	45	30	23	20	19	17	16	15	14	13	12	11	10	9	8	7
		50	38	33	31	28	26	25	23	22	20	19	17	15	14	13
20,000	18	12	9	8	8	7	6	6	6	5	5	5	4	4	3	3
	54	36	27	24	22	20	19	18	16	15	14	13	12	11	10	9
		60	45	41	38	35	32	30	28	26	24	22	20	18	16	15
30,000	22	14	11	10	9	8	8	7	6	6	6	5	5	4	4	4
	65	43	33	30	27	25	23	22	20	19	17	16	14	13	12	11
			54	49	45	42	39	36	33	31	29	27	24	22	20	18
40,000	27	18	14	12	11	10	10	9	8	8	7	7	6	5	4	4
		54	41	37	34	31	29	27	25	23	21	20	18	16	15	14
			68	62	57	52	48	45	42	39	36	34	31	27	25	23
50,000	35	23	18	16	15	13	12	12	11	10	9	9	8	7	6	6
		70	52	48	44	40	37	35	32	30	28	26	23	21	19	18
						67	62	58	54	50	47	44	39	35	32	29
60,000	45	30	22	20	19	17	16	15	14	13	12	11	10	9	8	7
			67	61	56	52	48	45	41	38	36	34	30	27	24	22
									69	64	60	56	50	45	41	37

TABLE 11 **PREDICTED FIRST MAXIMUM PITCH (DEGREES)**

217-lb Mk 86 Low Drag Practice Bomb (Wet Sand Filled)

Upper Figure: 0.5 In. Moment Arm — Center Figure: 1.5 In. Moment Arm — Lower Figure: 2.5 In. Moment Arm

Altitude Above Sea Level (Feet)	True Airspeed (Knots)															
	100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	14 42 70	9 28 47	7 21 35	6 19 32	6 18 29	5 16 27	5 15 25	5 14 23	4 13 22	4 12 20	4 11 19	4 11 18	3 9 16	3 8 14	3 8 13	3 7 12
10,000	16 49	11 33 55	8 25 41	8 22 37	7 21 34	6 19 32	6 18 29	5 16 27	5 15 25	5 14 23	4 13 22	4 12 21	4 11 18	3 10 16	3 9 15	3 8 14
20,000	20 59	13 40 66	10 30 49	9 27 45	8 25 41	8 23 38	7 21 35	7 20 33	6 18 30	6 17 28	5 16 26	5 15 25	4 13 22	4 12 20	4 11 18	3 10 16
30,000	24	16 48	12 36 60	11 33 55	10 30 50	9 28 46	9 26 43	8 24 40	7 22 37	7 21 34	6 19 32	6 18 30	5 16 27	5 14 24	4 13 22	4 12 20
40,000	30	21 60	15 45	14 41 69	13 38 63	12 35 58	11 32 54	10 30 50	9 28 46	9 26 43	8 24 40	8 23 38	7 20 34	6 18 30	5 16 27	5 15 25
50,000	39	26	20 59	18 53	16 49	15 45	14 42 70	13 39 65	12 36 60	11 33 56	10 31 52	10 29 49	9 26 43	8 23 39	7 21 36	7 20 33
60,000	50	33	25	23 69	21 63	19 58	18 54	17 50	15 47	14 43	13 40 67	13 38 63	11 34 56	10 30 50	9 28 46	8 25 42

TABLE 12

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

221-lb Mk 87 Low Drag Practice Bomb (Water Filled)

Upper Figure
0.5 In. Moment Arm

Center Figure
1.5 In. Moment Arm

Lower Figure
2.5 In. Moment Arm

ALTITUDE ABOVE SEA LEVEL (FEET)	True Airspeed (Knots) 100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	9	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2
	27	18	13	12	11	10	10	9	8	8	7	7	6	5	5	4
	45	30	22	20	19	17	16	15	14	13	12	11	10	9	8	7
10,000	11	7	5	5	4	4	4	4	3	3	3	3	2	2	2	2
	32	21	16	14	13	12	11	11	10	9	8	8	7	6	6	5
	53	35	26	24	22	20	19	18	16	15	14	13	12	11	10	9
20,000	13	9	6	6	5	5	5	4	4	4	3	3	3	3	3	2
	38	26	19	17	16	15	14	13	12	11	10	10	9	8	7	6
	64	43	32	29	27	25	23	21	20	18	17	16	14	13	12	11
30,000	16	10	8	7	7	6	6	5	5	4	4	4	3	3	3	3
	47	31	23	21	20	18	17	16	14	13	13	12	10	9	9	8
		52	39	36	33	30	28	26	24	22	21	20	17	16	14	13
40,000	20	13	10	9	8	8	7	7	6	6	5	5	4	4	4	3
	59	40	30	27	25	23	21	20	18	17	16	15	13	12	11	10
		66	49	45	41	38	35	33	30	28	26	25	22	20	18	17
50,000	26	17	13	12	11	10	9	9	8	7	7	6	6	5	5	4
		51	39	35	28	26	25	24	24	22	21	19	17	15	14	13
			64	58	54	49	46	43	40	37	34	32	29	26	23	21
60,000	33	22	17	15	14	13	12	11	10	10	9	8	7	7	6	6
		67	50	45	42	38	36	33	31	29	27	25	22	20	18	17
					69	64	60	56	51	48	44	42	37	33	30	28

TABLE 13

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

333-lb Mk 87 Low Drag Practice Bomb (Wet Sand Filled)

Upper Figure: 2.0 In. Moment Arm — Center Figure: 3.0 In. Moment Arm — Lower Figure: 4.0 In. Moment Arm

Altitude Above Sea Level (Feet)	True Airspeed (Knots) 100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	39	26	19	18	16	15	14	13	12	11	10	10	9	8	7	6
	58	39	29	27	24	22	21	19	18	17	16	15	13	12	11	10
		52	39	35	32	30	28	26	24	22	21	19	17	15	14	13
10,000	46	30	23	21	19	18	16	15	14	13	12	11	10	9	8	8
	68	45	34	31	28	26	25	23	21	19	18	17	15	14	13	11
		61	45	42	38	35	33	30	28	26	24	23	20	18	17	15
20,000	55	37	27	25	22	21	20	18	17	16	15	14	12	11	10	9
		55	41	38	34	32	30	27	25	24	22	21	19	16	15	14
			55	50	46	42	39	37	34	31	29	27	25	22	20	18
30,000	63	45	33	31	28	26	24	22	21	19	18	17	15	13	12	11
		67	50	46	42	39	36	33	31	29	27	25	23	20	18	17
			67	61	56	51	48	45	41	38	36	33	30	27	25	22
40,000		56	42	39	35	33	30	28	26	24	23	21	19	17	16	14
			63	58	53	49	45	42	39	36	34	32	28	25	23	21
					70	65	60	56	52	48	45	42	38	34	31	28
50,000			55	50	46	42	39	37	34	31	29	27	25	22	20	18
					68	63	59	55	51	47	44	41	37	33	30	27
									68	62	58	55	49	44	40	36
60,000				65	59	54	51	47	44	40	38	35	32	28	26	24
									66	61	57	53	48	42	39	35
													64	56	51	47

TABLE 14

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

458-lb Mk 88 Low Drag Practice Bomb (Water Filled)

Upper Figure: 0.5 In. Moment Arm
Center Figure: 1.5 In. Moment Arm
Lower Figure: 2.5 In. Moment Arm

ALTITUDE ABOVE SEA LEVEL (FEET)	True Airspeed (Knots) 100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	5	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1
	15	10	8	7	6	6	5	5	5	4	4	4	3	3	3	3
	25	17	12	11	10	10	9	8	8	7	7	6	6	5	5	4
10,000	6	4	3	3	2	2	2	2	2	2	2	2	1	1	1	1
	18	12	9	8	7	7	6	6	5	5	5	4	4	4	3	3
	29	20	15	13	12	11	10	10	9	8	8	7	7	6	5	5
20,000	7	5	4	3	3	3	3	2	2	2	2	2	2	1	1	1
	22	14	11	10	9	8	8	7	7	6	6	5	5	4	4	4
	36	24	18	16	15	14	13	12	11	10	10	9	8	7	7	6
30,000	9	6	4	4	4	3	3	3	3	3	2	2	2	2	2	2
	26	18	13	12	11	10	9	9	8	8	7	7	6	5	5	4
	44	29	22	20	18	17	16	15	14	13	12	11	10	9	8	7
40,000	11	7	6	5	5	4	4	4	3	3	3	3	2	2	2	2
	33	22	17	15	14	13	12	11	10	10	9	8	7	7	6	6
	56	37	28	25	23	21	20	19	17	16	15	14	12	11	10	9
50,000	15	10	7	7	6	6	5	5	4	4	4	4	3	3	3	3
	44	29	22	20	18	17	16	15	13	12	12	11	10	9	8	7
		48	36	33	30	28	26	24	22	21	19	18	16	15	13	12
60,000	19	13	9	9	8	7	7	6	6	5	5	5	4	4	3	3
	57	38	27	26	24	22	20	19	17	16	15	14	13	11	10	9
		63	47	43	39	36	34	32	29	27	25	24	21	19	17	16

TABLE 15

PREDICTED FIRST MAXIMUM PITCH (DEGREES)

783-lb Mk 88 Low Drag Practice Bomb (Wet Sand Filled)

Upper Figure: 0.5 In. Moment Arm — Center Figure: 1.5 In. Moment Arm — Lower Figure: 2.5 In. Moment Arm

ALTITUDE ABOVE SEA LEVEL (FEET)	True Airspeed (Knots) 100	150	200	220	240	260	280	300	325	350	375	400	450	500	550	600
1,000	9	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2
	27	18	14	12	11	10	10	9	8	8	7	7	6	5	5	5
	45	30	23	21	19	17	16	15	14	13	12	11	10	9	8	8
10,000	11	7	5	5	4	4	4	4	3	3	3	3	2	2	2	2
	32	21	16	15	13	12	11	11	10	9	9	8	7	6	6	5
	53	35	27	24	22	20	19	18	16	15	14	13	12	11	10	9
20,000	13	9	6	6	5	5	5	4	4	4	3	3	3	3	2	2
	39	26	19	18	16	15	14	13	12	11	10	10	9	8	7	6
	64	43	32	29	27	25	23	21	20	18	17	16	14	13	12	11
30,000	16	10	8	7	7	6	6	5	5	4	4	4	4	3	3	3
	47	31	24	22	20	18	17	16	15	13	13	12	11	9	9	8
		52	39	36	33	30	28	26	24	22	21	20	18	16	14	13
40,000	20	13	10	9	8	8	7	7	6	6	5	5	4	4	4	3
	59	40	30	27	25	23	21	20	18	17	16	15	13	12	11	10
		66	49	45	41	38	36	33	31	28	26	25	22	20	18	16
50,000	26	17	13	12	11	10	9	9	8	7	7	6	6	5	5	4
		51	38	35	32	20	28	26	24	22	21	19	17	15	14	13
			64	59	53	49	46	43	40	37	34	32	29	26	23	21
60,000	33	22	17	15	14	13	12	11	10	9	9	8	7	7	6	6
		66	50	45	41	38	36	33	31	28	27	25	22	20	18	17
					69	64	59	55	51	47	44	41	37	33	30	28

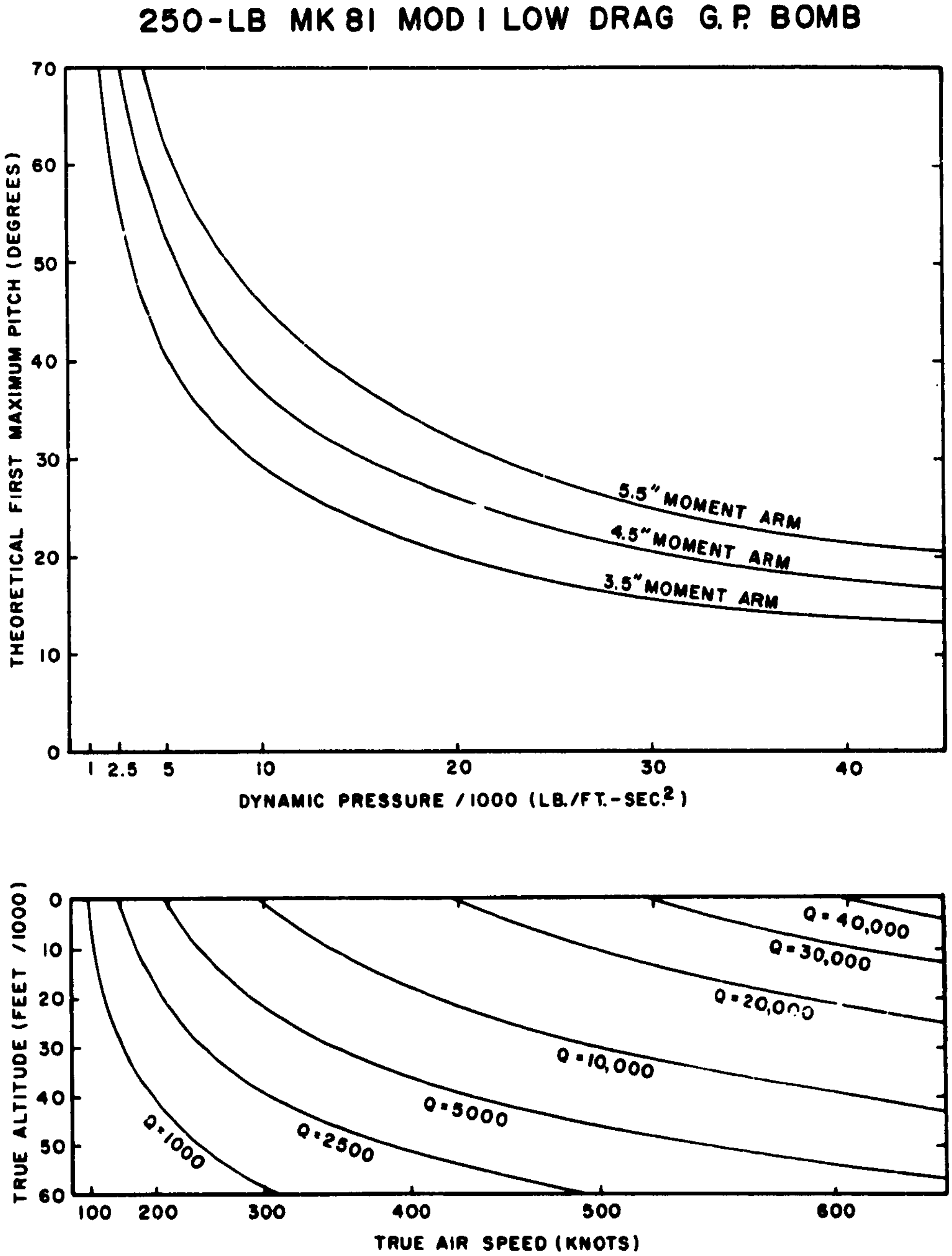

250-LB MK 81 MOD 1 LOW DRAG G.P. BOMB
THEORETICAL FIRST MAXIMUM PITCH (DEGREES)
70
60
50
40
30
20
10
0
1
2.5
5
10
20
30
40
DYNAMIC PRESSURE / 1000 (LB./FT.-SEC.²)
5.5" MOMENT ARM
4.5" MOMENT ARM
3.5" MOMENT ARM
TRUE ALTITUDE (FEET / 1000)
0
10
20
30
40
50
60
100
200
300
400
500
600
TRUE AIR SPEED (KNOTS)
Q = 40,000
Q = 30,000
Q = 20,000
Q = 10,000
Q = 5000
Q = 2500
Q = 1000

FIGURE 7

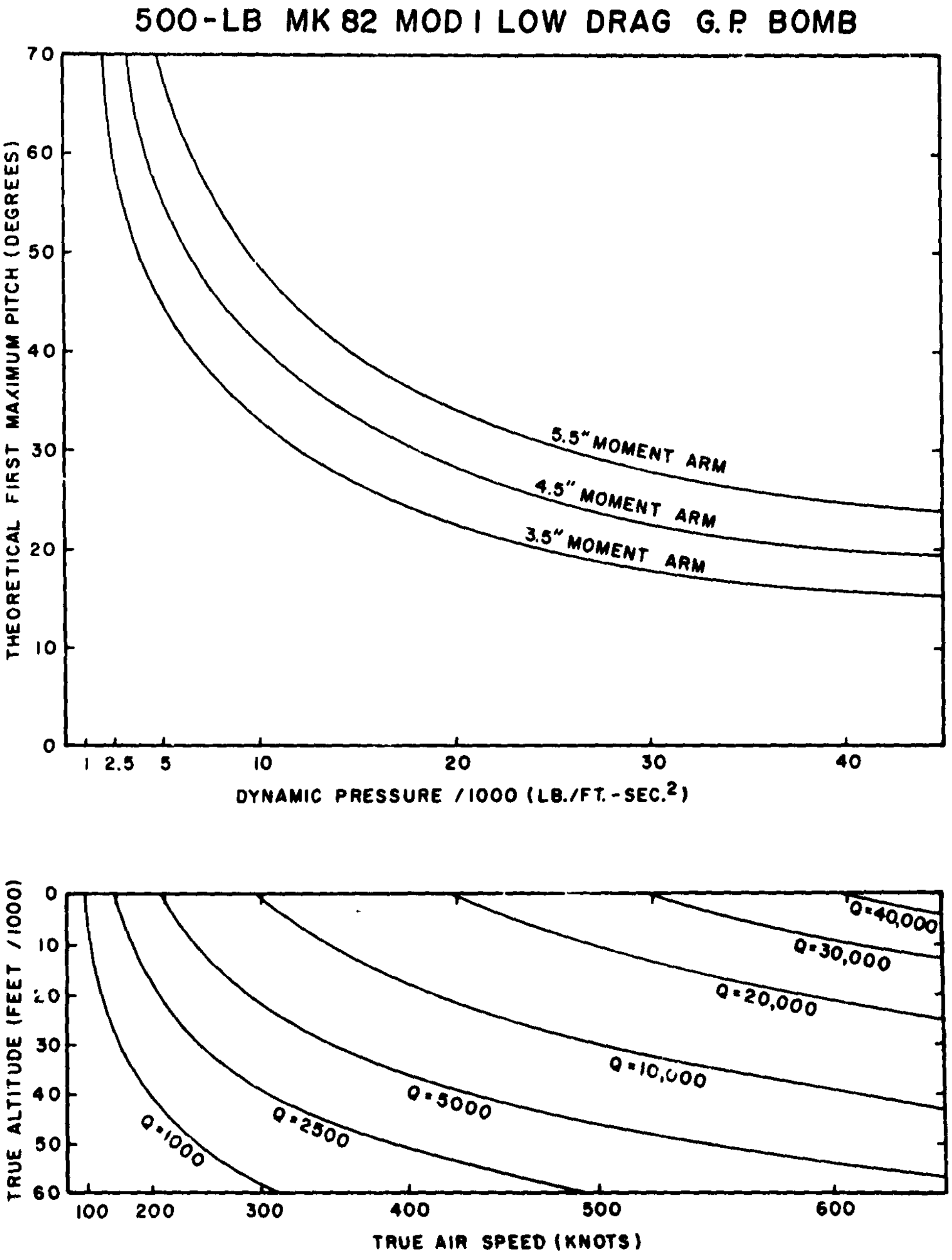
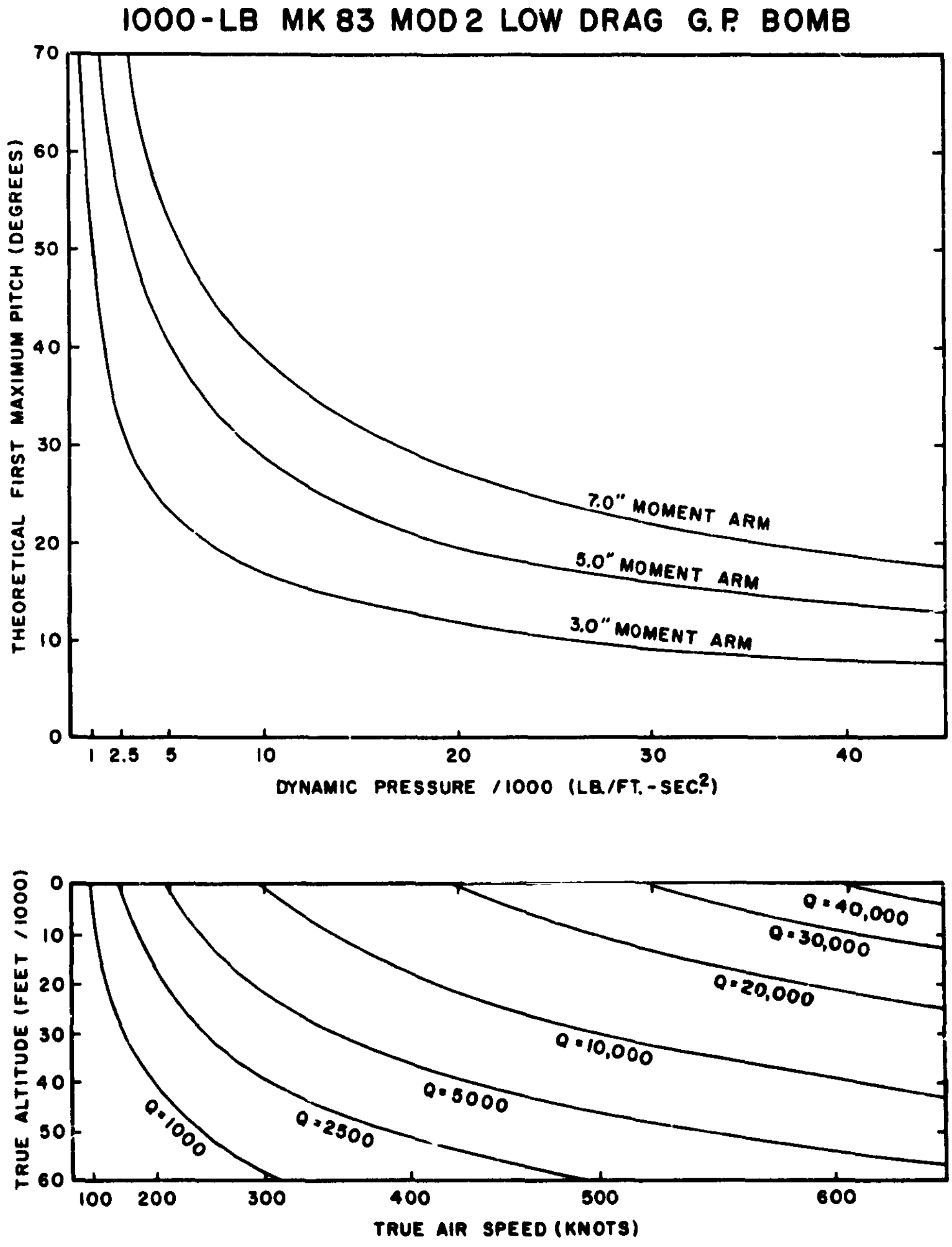

500-LB MK 82 MOD I LOW DRAG G.P. BOMB
THEORETICAL FIRST MAXIMUM PITCH (DEGREES)
70
60
50
40
30
20
10
0
1
2.5
5
10
20
30
40
DYNAMIC PRESSURE /1000 (LB./FT.-SEC.^{2})
5.5" MOMENT ARM
4.5" MOMENT ARM
3.5" MOMENT ARM
TRUE ALTITUDE (FEET /1000)
0
10
20
30
40
50
60
100
200
300
400
500
600
TRUE AIR SPEED (KNOTS)
Q=1000
Q=2500
Q=5000
Q=10,000
Q=20,000
Q=30,000
Q=40,000

FIGURE 8



1000-LB MK 83 MOD 2 LOW DRAG G.P. BOMB
THEORETICAL FIRST MAXIMUM PITCH (DEGREES)
70
60
50
40
30
20
10
0
7.0" MOMENT ARM
5.0" MOMENT ARM
3.0" MOMENT ARM
1
2.5
5
10
20
30
40
DYNAMIC PRESSURE /1000 (LB./FT.-SEC.^{2})
TRUE ALTITUDE (FEET /1000)
0
10
20
30
40
50
60
Q=40,000
Q=30,000
Q=20,000
Q=10,000
Q=5000
Q=2500
Q=1000
100
200
300
400
500
600
TRUE AIR SPEED (KNOTS)

FIGURE 9

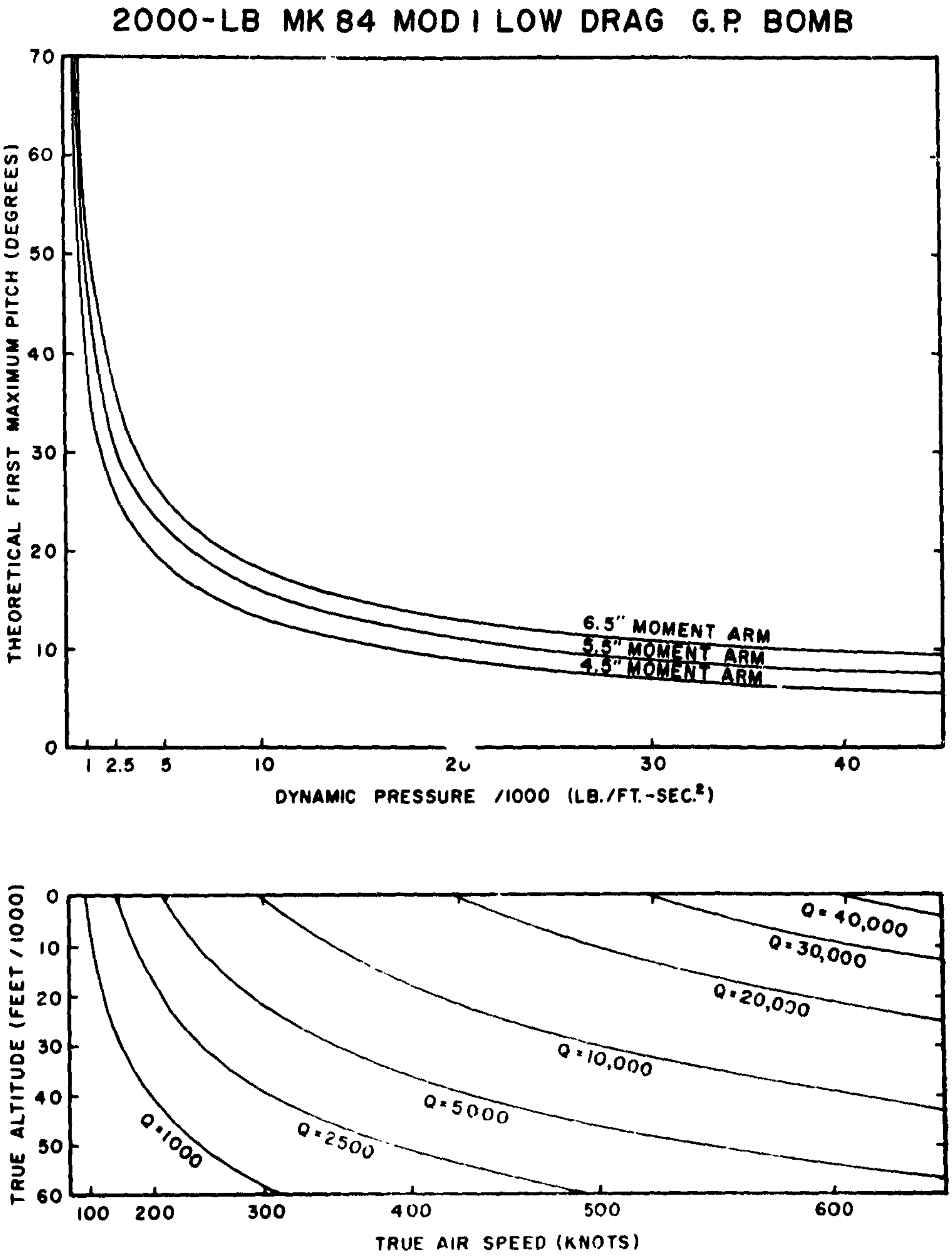

2000-LB MK 84 MOD I LOW DRAG G.P. BOMB
THEORETICAL FIRST MAXIMUM PITCH (DEGREES)
0
10
20
30
40
50
60
70
6.5" MOMENT ARM
5.5" MOMENT ARM
4.5" MOMENT ARM
1
2.5
5
10
20
30
40
DYNAMIC PRESSURE /1000 (LB./FT.-SEC.²)
TRUE ALTITUDE (FEET / 1000)
Q=40,000
Q=30,000
Q=20,000
Q=10,000
Q=5000
Q=2500
Q=1000
100
200
300
400
500
600
TRUE AIR SPEED (KNOTS)

FIGURE 10

141-LB MK 86 LOW DRAG PRACTICE BOMB (WATER FILLED)

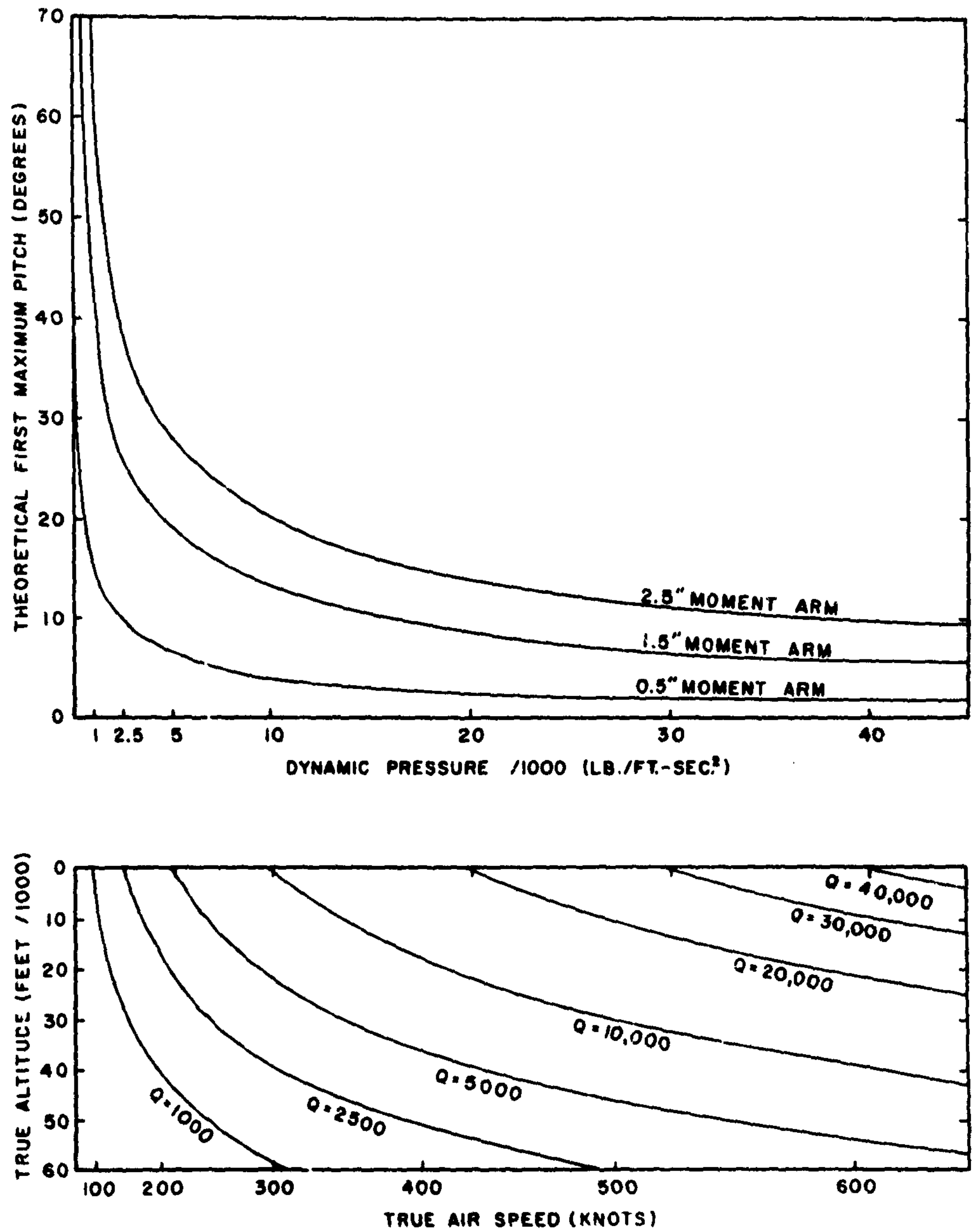


FIGURE 11

217-LB MK 86 LOW DRAG PRACTICE BOMB (WET SAND FILLED)

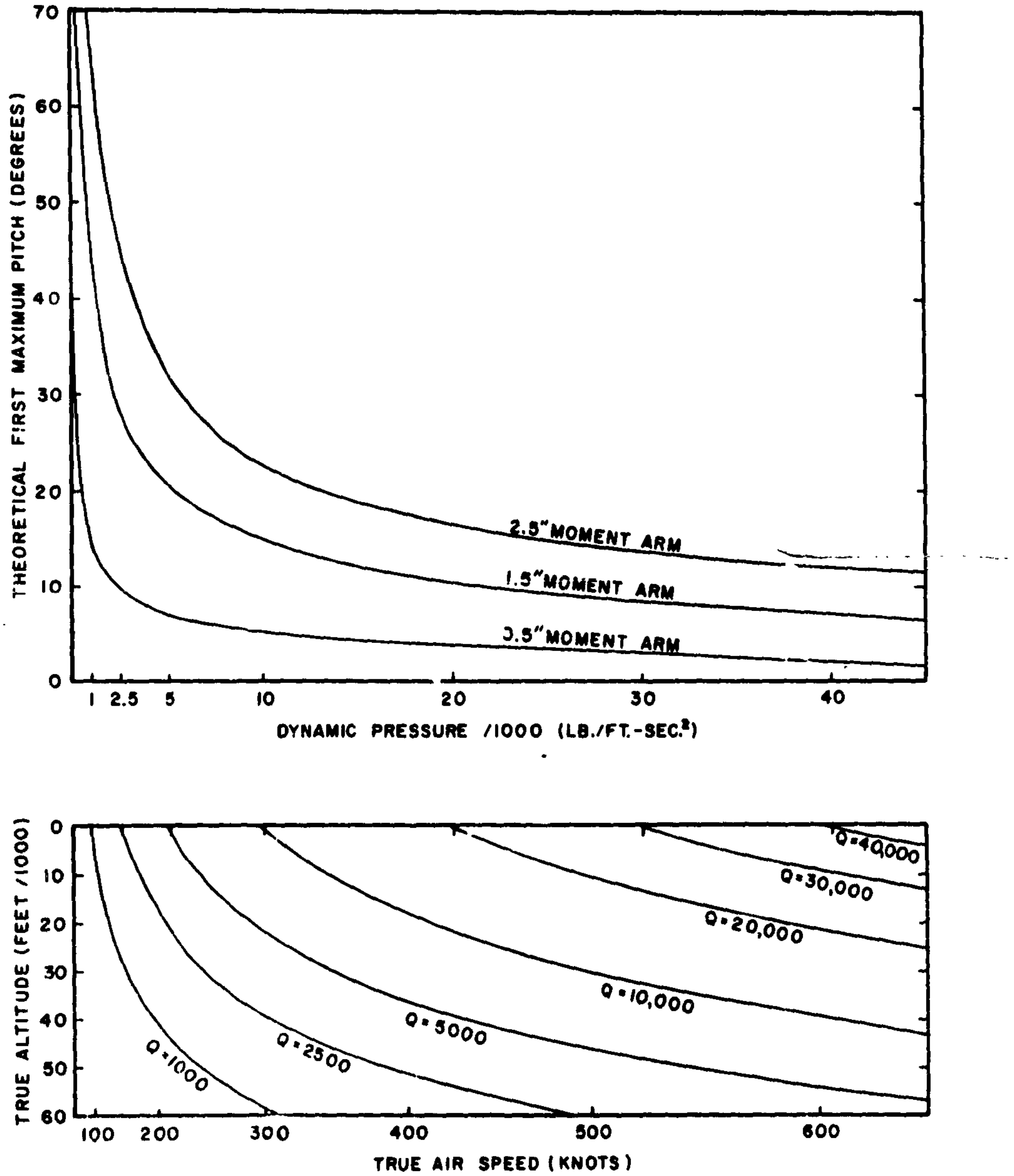


FIGURE 12

CONFIDENTIAL

221-LB MK 87 LOW DRAG PRACTICE BOMB (WATER FILLED)

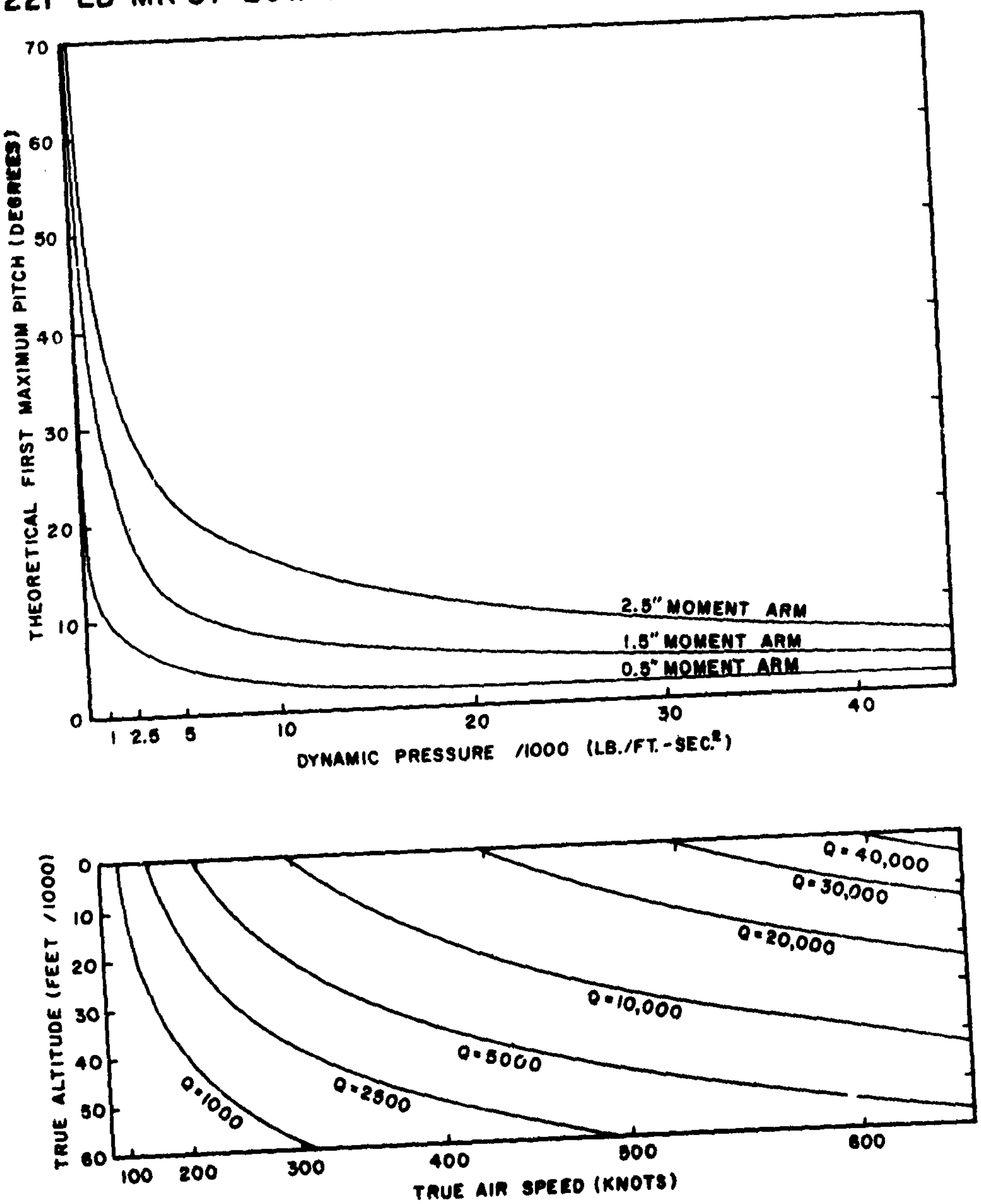
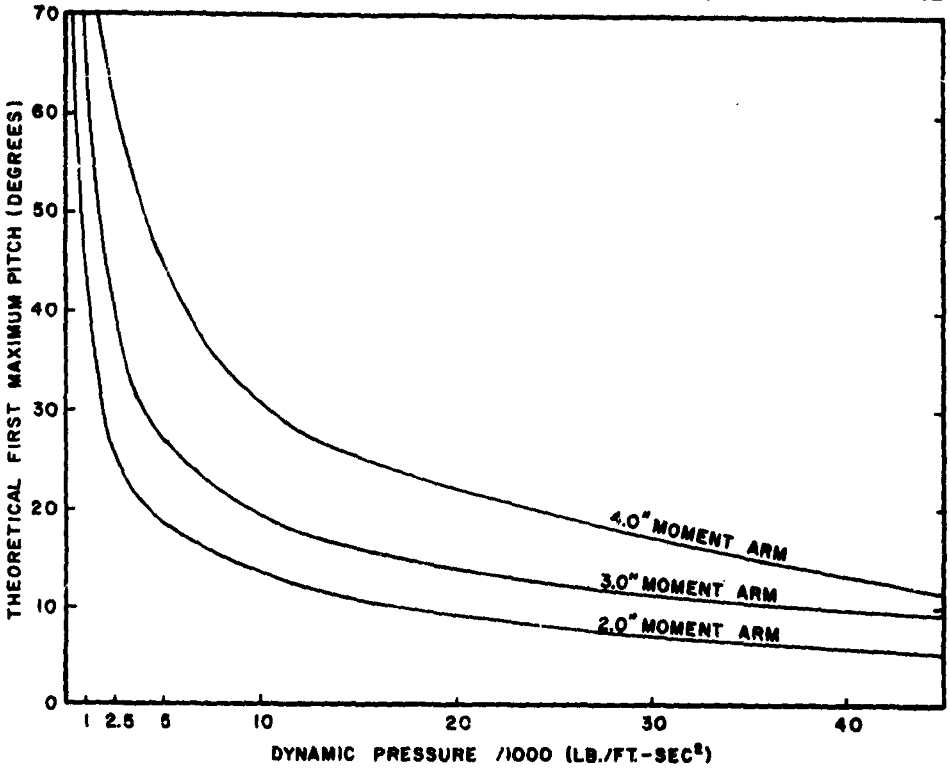


FIGURE 13

CONFIDENTIAL

333-LB MK 87 LOW DRAG PRACTICE BOMB (WET SAND FILLED)



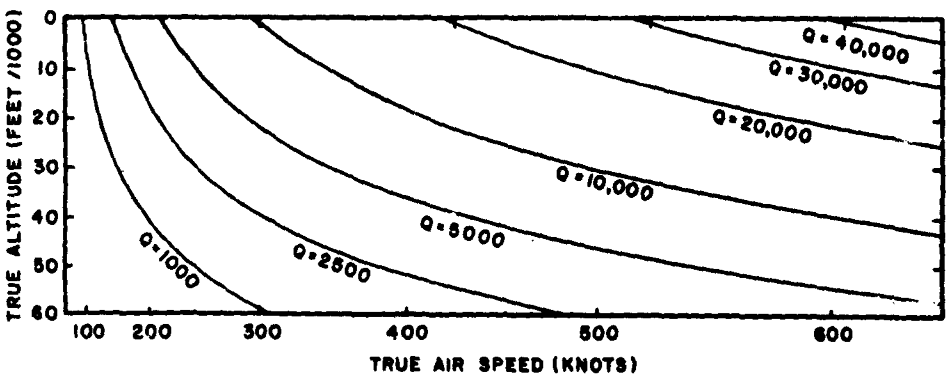


FIGURE 14

458-LB MK 88 LOW DRAG PRACTICE BOMB (WATER FILLED)

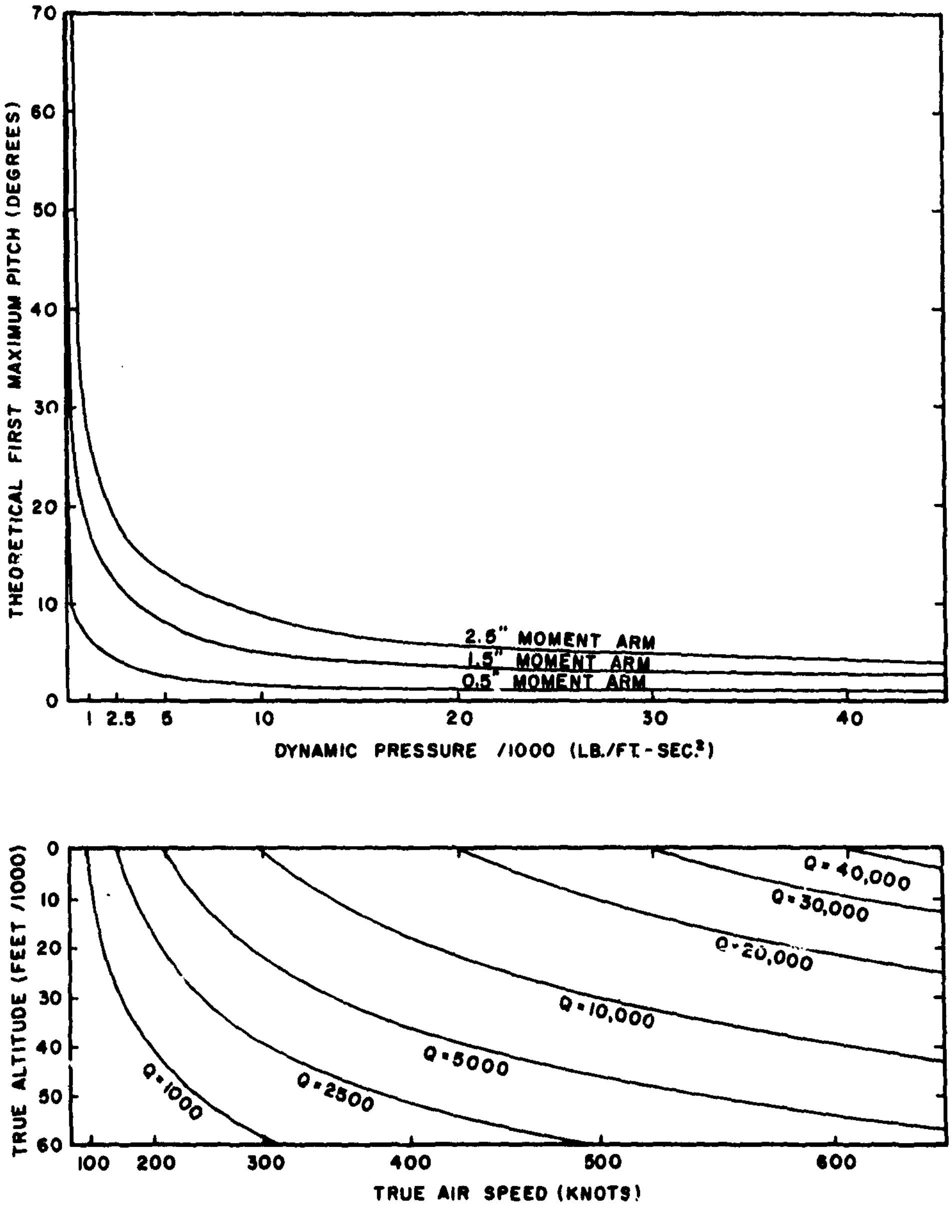


FIGURE 15

783-LB MK 88 LOW DRAG PRACTICE BOMB (WET SAND FILLED)

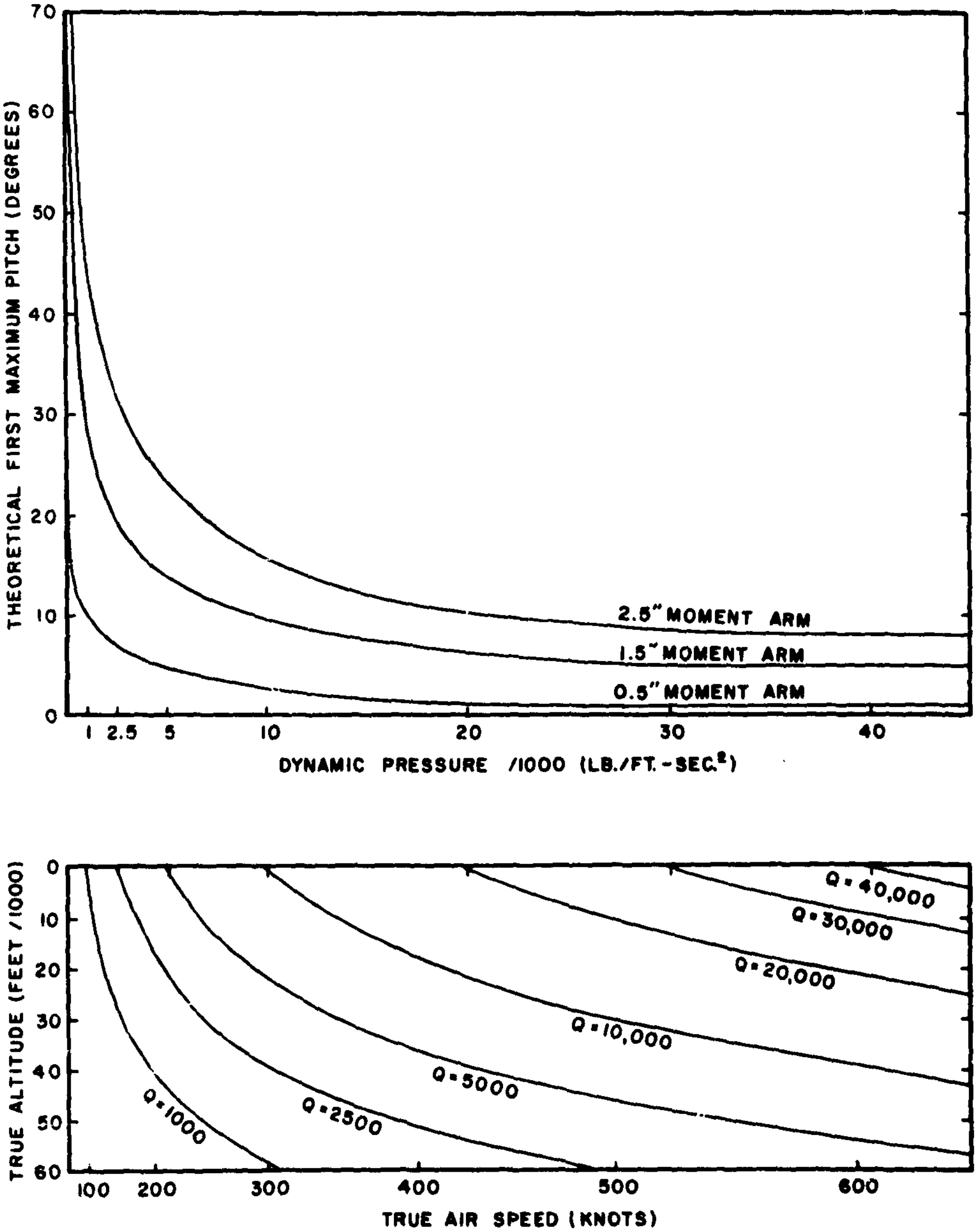


FIGURE 16

CONFIDENTIAL

THEORETICAL PREDICTIONS OF THE FIRST MAXIMUN PITCH OF LOW DRAG BOMBS RELEASED FROM A3D AIRCRAFT IN HORIZONTAL FLIGHT (U).

NWL REPORT NO. 1[illegible]3

CONFIDENTIAL